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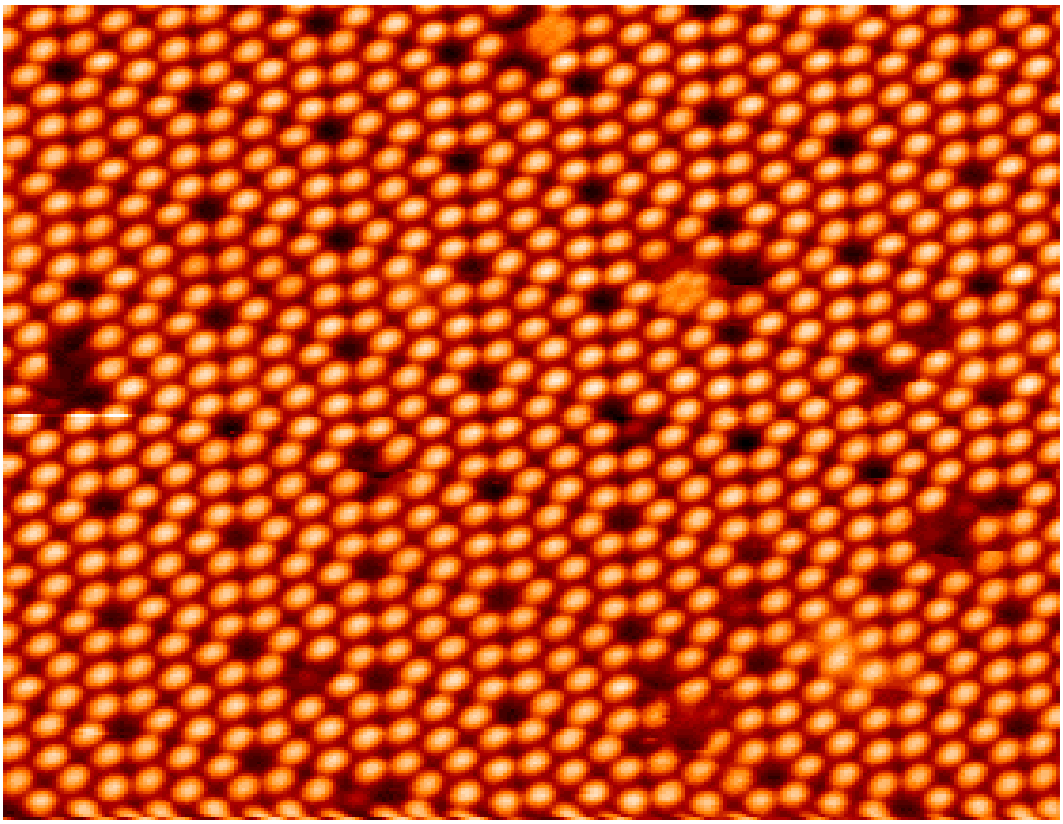

ARKANSAS ACADEMY OF SCIENCE
ARKANSAS TECH UNIVERSITY
DEPARTMENT OF PHYSICAL SCIENCES
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PAST PRESIDENTS OF THE ARKANSAS ACADEMY OF SCIENCE

Charles Brookover	1917	C. E. Hoffman	1959	Paul Sharrah	1984
Dwight M. Moore	1932-33, 1964	N. D. Buffaloe	1960	William L. Evans	1985
Flora Haas	1934	H. L. Bogan	1961	Gary Heidt	1986
H. H. Hyman	1935	Truman McEver	1962	Edmond Bacon	1987
L. B. Ham	1936	Robert Shideler	1963	Gary Tucker	1988
W. C. Munn	1937	L. F. Bailey	1965	DavidChittenden	1989
M. J. McHenry	1938	James H. Fribourgh	1966	Richard K. Speairs, Jr.	1990
T. L. Smith	1939	Howard Moore	1967	Robert Watson	1991
P. G. Horton	1940	John J. Chapman	1968	Michael W. Rapp	1992
L. A. Willis	1941-42	Arthur Fry	1969	Arthur A. Johnson	1993
L. B. Roberts	1943-44	M. L. Lawson	1970	George Harp	1994
Jeff Banks	1945	R. T. Kirkwood	1971	James Peck	1995
H. L. Winburn	1946-47	George E. Templeton	1972	Peggy R. Dorris	1996
E. A. Provine	1948	E. B. Whittlake	1973	Richard Kluender	1997
G. V. Robinette	1949	Clark McCarty	1974	James Daly	1998
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W. W. Nedrow	1956	Henry W. Robison	1981	Betty Crump	2005
Jack W. Sears	1957	John K. Beadles	1982	Stanley Trauth	2006
J. R. Mundie	1958	Robbin C. Anderson	1983	David Saugey	2007
				Collis Geren	2008

INSTITUTIONAL MEMBERS

The Arkansas Academy of Science recognizes the support of the following institutions through their Institutional Membership in the Academy.

ARKANSAS STATE UNIVERSITY, Jonesboro
ARKANSAS TECH UNIVERSITY, Russellville
JOHN BROWN UNIVERSITY, Siloam Springs
SOUTHERN ARKANSAS UNIVERSITY, Magnolia
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UNIVERSITY OF ARKANSAS AT PINE BLUFF
UNIVERSITY OF THE OZARKS, Clarksville
UNIVERSITY OF ARKANSAS AT FORT SMITH

EDITORIAL STAFF

COVER: Scanning Tunneling Microscope Image of Silicon. Photo from Dan Bullock, ATU

ARKANSAS ACADEMY OF SCIENCE 2008

APRIL 11-12, 2008
92ND ANNUAL MEETING

Henderson State University
Arkadelphia, Arkansas

JOURNAL
ARKANSAS ACADEMY OF SCIENCE

Annual Meeting 11-12 April 2008
Henderson State University

Secretary's Report

MINUTES OF THE 92ND MEETING

ARKANSAS ACADEMY OF SCIENCE
92st ANNUAL MEETING
SUMMARY OF 1st and 2nd BUSINESS MEETINGS
Henderson State University
April 11-12, 2008

1. Collis Geren, President of the AAS called the meetings to order.

2. Local Organizing Committee: The LOC chair, Renn Tumlison reported that the meeting had 160 registered participants. There were 83 oral and 49 poster presentations. Brett Serviss announced the student awards with special thanks to the faculty judges:

Undergraduate Physical Science
1st Place: Paul Minor, 2nd Place: Jason R. Robison, 3rd Place: Jerakaycia D. Boman

Graduate Physical Science
1st Place: Allan Thomas

Undergraduate Life Science
1st Place: Allicia Kellogg, 2nd Place: Jerred Caskey

Graduate Life Science
1st Place: C. Brian Caldwell, 2nd Place: Jacy L. Wagnon, 3rd Place: Lauren P. Blair

Undergraduate Environmental Science
1st Place: Nicole Freeman, 2nd Place: April Helms, 3rd Place: Michael Gilbert

Graduate Environmental Science
1st Place: Tiffany A. Whitsitt,
2nd Place: Nathan J. Wentz

Undergraduate Poster
1st Place: Russell Cline, 2nd Place: Wes Greer

Graduate Poster
1st Place: Karen Vale

3. Secretary/Newsletter Editor/Webmaster: Jeff Robertson: Minutes from the 2007 November Executive Committee meeting were distributed and minutes from the 2007 April membership business meetings were distributed for review and accepted. There are currently 125 AAS members, 47 of which are life members. The current public portal website is paid for through 2017 (http://www.ArkansasAcademyofScience.org).

4. Treasurer/Auditor: Mostafa Hemmati: The "books" maintained by the Academy Treasurer were reviewed by members of the Executive Committee and found to be good financial records kept with excellent integrity and showing no inconsistencies or irregularities with only an $11 imbalance hardly worth mentioning (The financial status of the Academy is in an Appendix found elsewhere in this JAAS volume for review). A request for ~$100 to prepare taxes for the Academy has become necessary with new tax law.

5. Historian: Henry Robison: The AAS annual meeting this year at Henderson State University will be the 92nd meeting of the AAS and the 6th time at HSU. HSU previously hosted the meeting in 1935, '41, '68 (jointly with OBU), '82, and '93). This is the first time it has been held jointly with the Arkansas Undergraduate Research Conference Henry Robison is stepping down after 25 years of service as the AAS historian.

6. Nominations Committee: Mostafa Hemmati: The committee submitted candidates for Historian (Collis Geren) who was elected by acclamation and ballots were cast for Vice-President between Jeff Robertson and Derek Sears. Jeff Robertson was elected to serve and will be President-elect in 2009 and President in 2010.

7. Journal Editor-in-Chief: Stan Trauth: Reported that the printing of Volume 61 went smoothly this year. I continue to use Bank and Business Solutions, 1208 Falls Street, Jonesboro, AR 72401, as the publisher of the Journal. Roger Williams can be reached via office (1.800.442.2108) phone. His on-line address, www.prinformance.com, can be accessed for purchasing CDs and PDFs of Journal articles. Volume 61 encompassed a total of 146 pages and included 16 feature articles and 7 general notes. A total of 195 copies were produced at a cost of $8,196.84. I provided revised manuscripts to the Williams' publishing team (BBS) via CDs and hard copies from early October to late December, 2007. PDFs were generated for each accepted manuscript by Jeremy Baker of BBS and provided to me from late January to early March, 2008. The submission of the PDFs as galley proofs greatly expedited the editing process. The final galley proof of the Journal was printed during the first week of April. I received Volume 61 on April 7, 2008. Address labels for current membership were placed on copies April 9.

   As I depart the Editor-in-Chief's position, I wish to thank all AAS officers and the general membership for supporting my efforts over the years to produce the highest quality journal possible. It has truly been a memorable experience. I especially want to thank Joy Trauth for her dedication as the Assistant Editor. She read EVERY MANUSCRIPT published during the past 15 years. She can also be credited with a majority of the work related to updating the recent Instructions for Authors and Publications Policies for the Journal. And finally, I request that the AAS continue support of $600 for the Editorial Assistant position and $200 to the Editor-in-Chief for assorted publishing expenses with $700 for the Managing Editor.

8. Journal (JAAS) Managing Editor: Chris T. McAllister: There were 29 manuscripts submitted (for comparison 37 were submitted last year, a decrease of 22%) for consideration of publication in volume 61 (2007) of the JAAS at the ATU-Russellville meeting in April 2007. Not all papers were sent out for review. Three papers (10%) fell under the category of Science Education and returned to author(s) with a friendly explanation letter stating that JAAS currently doesn't publish these types of papers. Both Managing Editor and Editor-in-Chief were in agreement on this matter.

   Twenty-six papers were sent out in early summer to reviewers and Assoc. Editors and returned between July-September 2007. There was some tardiness in getting back a couple of reviews, as usual. A couple of reviewers did not send back a review at all so one of the Editors served as a reviewer. However, the review process proceeded nicely and papers were processed in a timely manner, much better and faster than in years past!—isn't that the way it is supposed to be in your last year of editorship? An Asst. Editor read mss. for style, grammar, format, etc. Authors were then contacted via letter by me in August or September 2007 as to whether their paper was accepted tentatively and needed minor or major revision or whether their paper was outright rejected. Of the papers sent out for peer review, two (8%) were outright rejected. There were several that required little revision (minor revision) while others required major revisions. In two cases, one reviewer suggested rejection while the other suggested either minor or major revision. In those cases, the Managing Editor made the call to accept those papers pending major revision. Three papers originally submitted as feature articles were suggested to reduce them to general notes. Authors were asked to turn the revision around in 48-72 hours, and send back to Dr. Trauth, Editor-in-Chief, by late September, preferably by overnight mail. As noted, two papers were outright rejected. These did not report any new information or were in need of additional supportive data. All reviewers noted this important necessity and I concurred. In the end, they simply did not report any new or publishable data. During Jan-Feb. 2008, I received PDF's of papers to be published in the journal. I made initial corrections and forwarded them on to authors for their revisions/corrections. Authors were asked to make a quick turnaround and send that on to Dr. Trauth within 48-72 hrs. Two authors never sent PDF's to Stan for processing. Stan Trauth received corrected PDF's from authors and made final corrections before forwarding those on to the printer in Jonesboro. See volume 61 of the JAAS for a breakdown of papers published.

Thanks to the following Associate/Assistant Editors for their help in processing mss for volume 61: Dr. Robert Engelken, ASU, Dr. Joy Trauth, ASU, (and 46 anonymous reviewers!)

I want to thank everyone for their support during my tenure (2003-2007, volumes 57-61) as Managing Editor of JAAS. It has been a pleasure working as a two-man editorial "team" with Stanley Elwood Trauth and I am glad to have been of service to the Academy during this time. This meeting is especially important as my initial membership in AAS was 30 years ago in 1978.

9. Arkansas Science Fair Association: Mark Bland: The State Science Fair was held April 4-5, 2008 at UCA with 222 students from 28 different H.S. registering to present 209 projects evaluated by 60 judges. A summary listing of awards in each category was presented to the Academy. A request of $400 to support student awards was made on behalf of the State Science Fair Association.

10. Junior Academy of Science: Nolan Carter: The time frame of our two meetings makes logistics a bit difficult to coordinate having the AJAS winner present, since the AJAS winner is selected less than one week prior to the AAS meeting. A permanent time slot should be reserved in the future at each annual AAS meeting for this purpose. I could talk to the first place winner at the AJAS awards ceremony to make arrangements. If the first place finisher is unable to present, I would give the opportunity to the second or third place finisher. The AJAS award winner should receive an invitation from the AAS president each year.

11. Arkansas Science Talent Search: Will Slaton: no report

12. Junior Science and Humanities Symposium: Linda Kondrick: The 42nd Arkansas Junior Science and Humanities Symposium is scheduled for March 14, 15, and 16, 2008. We are once again asking for a pledge of support from the Arkansas Academy of Science in the amount of $100.00

The National JSHS Office supports five students and the director to attend the National JSHS program, which will be held April 30 - May 4, 2008 in Orlando, Florida. Because of the generosity of our local contributors, like AAS, Arkansas is able to send a sixth delegate to this informative and inspirational five-day program. Our students always come home with a new vision for the opportunities that await them in a science, math, and engineering careers.

The support of the Arkansas Academy of Science has also encouraged the presentation of original research in poster format at the regional symposium held at ATU. Because of your support we are able to offer small cash awards for up to 12 winners in our research poster session. This event encourages many more students to participate in the three-day symposium and all of its educational activities than would otherwise attend.

Thanks again to the AAS for help in making Arkansas JSHS an unqualified success year after year. We are counting on your continued support of this very fine program that encourages and rewards science students and teachers here in Arkansas.

13. Committee Reports: Biota Committee: Doug James: I have finally found a graduate student who seems likely to stick with the project, which involves inspecting and making corrections needed on the scanned version of Leo's hard copies of the lists. A former student of mine did all the scanning and cleaned up 12 lists. The present student wants to work over the summer. We have made arrangements with the web master for the Department of Biological Science, University of Arkansas, to install the lists on the departmental home page. The 12 lists indicated above will be there by the end of May 2008. All 49 of Leo's lists will be there by the end of summer 2008.

I still have $234 left from the appropriation the Academy gave the Biota Committee some time ago, used for funding the progress to date. This may be enough to cover the rest of the lists, but I am not sure. If possible, an added $200 would be welcomed. Any sums remaining would be used to insert the two or three new lists that have been submitted, and of course in recent years there have been new list and revised lists published the Journal. These have to be processed too.

The scheme is to get everything on the web and contact the various experts who first submitted the lists to inspect them for accuracy and currency. This activity will require use of the funds to make revisions.

I'm making a stab at how to title the list on the web page. My preliminary attempt is as follows.

The Arkansas Academy of Science
ARKANSAS BIOTA SURVEY
A project initiated by and now dedicated to the late
Leo J. Paulissen
Present Curator: Douglas A. James
Department of Biological Sciences
University of Arkansas
Fayetteville, AR 72701
Tel: 479-575-6364
Fax: 470-575-4010
E-mail: djames@uark.edu

The Biota Survey consists of a collection of checklists of biotic taxa occurring in Arkansas.

a. Development Committee: Betty Crump: The development committee reported on issues and ideas they have for two major goals, 1) recruitment and membership in the AAS, 2) increasing annual funding to support new initiatives and seek sponsorship opportunities. In addition a check for $1,000 was presented to the AAS from the Ouachita National Forest towards continued development of the AAS, with a commitment of $1,000 annually (as their budget allows). More institutional sponsors are solicited.

b. AAAS: Mostafa Hemmati reported that 4 students benefited from memberships to the AAAS, 2 H.S. and 2 college students received 1 year memberships on behalf of the Academy and will receive certificates as well as Science magazine.

14. New Business:

a. The entire contents of all previous editions of the JAAS have now been completely scanned under the initiative of Collis Geren and the UA library with a special recognition to Judy Ganson.

b. The JAAS Editor-in-Chief and Managing Editor jobs are going to be directed by Mostafa Hemmati, Ivan Still and Jeff Robertson for the upcoming journal. It is anticipated that Ivan Still and other players to be named later will handle managing editor duties as co-editors with Ivan Still eventually taking command as Editor-in-Chief. Mostafa Hemmati presented the new author instructions that will facilitate e-publishing and reduce the journal publication costs. A vote of confidence in publishing the journal this year was given to Mostafa Hemmati by the membership.

c. The announced dates of the 93rd Annual meeting as April 3-4, 2009 on the University of the Ozarks campus in Clarksville, Arkansas. Locations for 2010 (April 9-10) and beyond are solicited. Did someone say UACCB? Or perhaps there was an "amen" in the back from UALR?

d. An annual budget (not including costs directly associated with JAAS publication and the Annual Meeting expenses) was presented to the membership and approved. This included $4,150 for:

I. Sponsored Student Awards for AAS affiliations

1. Arkansas Science Talent Search (Will Slaton) $150
2. Arkansas State Science Fair Association (Mark Bland) $ 400
3. Arkansas Academy of Science annual meeting student awards $1,400
4. Arkansas Junior Academy (Nolan Carter) $250
5. Junior Science and Humanities Symposium (Linda Kondrick) $100

II. Correspondences:

1. JAAS Managing Editor and Associate Editors $500
2. Editor-in-Chief and Editorial Assistant $800
3. Secretary $200
4. Newsletter $100

III. Miscellaneous

1. Biota Committee $200
2. Treasurer (tax preparation) $100

TOTAL $4,200

e. AAS adopted the statement on evolution by AAAS that is posted on our website.

f. President asked that the AAS be more involved in consulting and being available to the legislature when and where appropriate.

g. Resolutions for the annual meeting were read to the membership (see Resolutions).

h. A motion to modify the publication guidelines of the JAAS to include Science Education Research was presented, discussed and tabled. Executive Committee to discuss the particular paper rejected

this year at fall meeting and present motion at next spring meeting for full discussion.

15. Awards were presented to Joy and Stan Trauth for their years of service with the JAAS, to Henry Robison for his 25 years as Historian and to outgoing President Collis Geren.

16. Closing: New president Joyce Hardin accepted the ceremonial gavel from outgoing president Collis Geren making him Past-president, Scott Kirkconnell President-elect and Jeff Robertson Vice-president.

Meetings adjourned.

Jeff Robertson, AAS Secretary

ARKANSAS ACADEMY OF SCIENCE
2009 FINANCIAL STATEMENT
October 15, 2008

Balance – October 15, 2008	**$53,787.07**
Balance – January 2, 2008	**$43,000.06**
Net Gain	**$10,787.01**

DISTRIBUTION OF FUNDS

Checking Account Bank of the Ozarks, Russellville, AR, 10-1-08	**$5,283.60**
Certificate of Deposit	
Life Membership Endowment, Bank of the Ozarks, Russellville, AR, 10-1-08 Maturity Date 11-11-09	**$14,431.03**
Dwight Moore Endowment Bank of the Ozarks, Russellville, AR, 10-1-08 Maturity Date 8-11-08	**$5,896.74**
Phoebe and George Harp Endowment Bank of the Ozarks, Russellville, AR, 10-1-08 Maturity Date 5-12-09	**$7,464.01**
Unrestricted Bank of the Ozarks, Russellville, AR Maturity Date 5-12-09	**$6,397.71**
Short Term CD Bank of the Ozarks, Russellville, AR, 10-1-08 Maturity Date 1-27-09	**$4,082.53**
Short Term CD Bank of the Ozarks, Russellville, AR, 10-1-08 Maturity Date 2-27-09	**$9,025.69**
Combined Interest (October 1, 2008)	$**1,205.76**
Total	**$53,787.07**

INCOME:

1. ANNUAL MEETING	**$3,148.11**
2. ENDOWMENT	**$100**
3. GIFT RECEIVED	
a. Betty Crump	$50
b. USDA Sponsorship	$1,000
	$1,050
4. INTEREST (Interest Earned Year to Date, October 1, 2008)	
a. Checking Account	$4.09
b. CD (added to the Checking)	$85.14
c. CD	$403.98
d. CD	$199.18
e. CD	$222.71
f. CD	$190.89
g. CD	$74.08
h. CD	$25.69
	$1,205.76
5. JOURNAL	
a. Subscription (40 copies)	$2,000
b. Page Charges	$12,966.67
	$14,966.67
6. JOURNAL CONTRIBUTION	**$200**

7. MEMBERSHIP

a. Associate	$15
b. Individual	$2,240
c. Life	$375
d. Sustaining	$35
	$2,665.00

8. MISCELLANEOUS INCOME

a. Check from David Davies	**$74.24**

TOTAL INCOME **$23,409.78**

EXPENSES

1. STUDENT AWARDS

a. Paul Minor	$100
b. Jason Robison	$50
c. Jerakaycia Boman	$50
d. Allan Thomas	$100
e. Allicia Kelog	$100
f. Jerred Caskey	$50
g. Brian Caldwell	$100
h. Jacy Wagnon	$50
i. Lauren Blair	$50
j. Nicole Freeman	$100
k. April Helms	$50
l. Michael Gilbert	$50
m. Tiffany Whitsitt	$100
n. Nathan Wentz	$50
o. Russell Cline	$50
p. Wes Greer	$25
q. Karen Vale	$50
	$1,125

2. AWARDS

a. Junior Science and Humanities Sym.	$100
b. Arkansas State Science Fair	$400
c. Arkansas Junior Academy of Science	$250
d. Arkansas Science Talent Search	$150
	$900

3. JOURNAL EXPENSES

a. Journal Expenses – Stan Trauth	$200
b. Vol. 61 Printing Cost	$8,196.84
c. Journal Mailing Cost – ATU	$142.60
d. Journal Digitalization Cost	$4,540
e. Journal Editorial Cost	$800
f. Journal Mailing Cost, Jeff Robertson	$25.25
	$13,904.69

4. NEWSLETTER **$57.81**

5. MISCELLANOUS EXPENSES

a. Total Cost of Five Plaques	$244.17
b. Mailing Cost	$15.06
c. Annual Dues, National Academies	$64.10
	$323.33

6. TRANSFER TO CD ($9,000 - $5,000) **$4,000**

TOTAL EXPENSES **$20,310.83**

APPENDIX A

2008 AAS Presentation Award Winners

GRADUATE STUDENT AWARDS

Poster Awards

1st Place: Karen Vale / UAM
Territoriality of male swamp rabbits (*Sylvilagus aquaticus*) in southeastern Arkansas.

Oral Presentation Awards

Graduate Environmental Science

1st Place: Tiffany A. Whitsitt / UAM
Small mammal community dynamics on a wetland restoration site in southeastern Arkansas

2nd Place: Nathan J. Wentz / ASU
Mussel inventory and population status of the Federally endangered *Potamilus capax* (Green 1832) in the Tyronza River, Arkansas

Graduate Life Science

1st Place: C. Brian Caldwell / UAMS
Angiographic variations in the Circle of Willis in the New Zealand white rabbit

2nd Place: Jacy L. Wagnon / UAMS
Processed MRNA, regulated by P38 kinase and ATF/CREB proteins, is required for hotspot meiotic recombination

3rd Place: Lauren P. Blair / UAMS
Using mass spectrometry to elucidate the structure of bacteriophage T4 helicase DDA

Graduate Physical Science

1st Place: Allan Thomas / UALR
Li Doped ZnO Nanowires Grown By a Low Temperature Electrochemical Process

UNDERGRADUATE STUDENT AWARDS

Poster Awards

1st Place: Russell Cline / UCA
Thickness determination using Rutherford backscattering of alpha-particles

2nd Place: Wes Greer / UA
Creating tools to study immunity in *Candida albicans*

Oral Presentation Awards

Undergraduate Environmental Science

1st Place: Nicole Freeman / HSU
A continuing investigation into the occurrence, establishment, and biology of seven, non-native, woody angiosperms in southwestern Arkansas

2nd Place: April Helms / HSU
Effects of indigenous communities and agriculture on coral reef composition in the western Gulf of San Blas, Panama

3rd Place: Michael Gilbert / UAM
Accuracy assessment of recreational and mapping grade GPS units in three different landscapes

Undergraduate Life Science

1st Place: Allicia Kellogg / UCA
Investigating the link between trichome and prickle development in R*ubus*

2nd Place: Jerred Caskey / SAU
Cretaceous sharks of southwest Arkansas

Undergraduate Physical Science

1st Place: Paul Minor / ASU
Organic chemical bath deposition of indium (III) sulfide

2nd Place: Jason R. Robison / UALR
Computer simulation of electrodynamic screens

3rd Place: Jerakaycia D. Boman / ATU
Synthesis and characterization of hydroxyapatite biomaterials

APPENDIX B
RESOLUTIONS

Arkansas Academy of Science
92nd Annual Meeting, 2008 Resolutions

Be it resolved that we, the membership of the Arkansas Academy of Science, offer our sincere appreciation to Henderson State University for hosting the 92nd annual meeting of the Arkansas Academy of Science, this year held jointly with the annual meeting of the Arkansas Undergraduate Research Conference. We thank the Local Arrangements Committee: Chair Dr. Renn Tumlison, Chair for AURC Dr. Marty Campbell, and Drs. Bray, Dunn, Engman, and Serviss; also the dedication of the webmaster, Kristen Benjamin, and support by Anna Smith and all of the student workers and staff, who collectively contributed to such a successful meeting. Appreciation is expressed for the use of these superior meeting facilities at Henderson State University, and the hospitality shown to us by HSU personnel. We especially thank our Keynote Speaker, Dr. Jeremy B. C. Jackson for his engaging keynote address which could have had the title, "The Triumph of Britney Spears", but, in fact, was entitled " Brave New Ocean" We thank Henderson State University for its donations to the Social and Banquet, which were both excellent and thoroughly enjoyed by all. We thank HSU President Dr. Charles Dunn for hosting the AAS and his welcome.

The Academy recognizes the important role assumed by Session Chairs and expresses sincere appreciation to: Mostafa Hemmati: Physics I chair, Wray Jones: Chemistry I chair, Allen Leible: Biomedicine I chair, Thomas Smith: Botany and Aquatic Biology chair, Jeff Robertson: Physics II chair, Janice O'Donnell: Chemistry II chair, Chris Guyer: Vertebrate Zoology and Environmental Science chair, J. D. Swanson: Botany II chair, Daniel Bullock: Physics III chair, Brett Serviss: Chemistry III chair, Troy Bray: Invert. Zool I chair, Henry Robison: Vert. Zool II chair, Charles Wu: Biomedicine II chair, Anwar Bhuiyan: Science potpourri chair, Henry Robison: Invert. Zool. II chair. We also recognize the contributions of the Judges who facilitate student participation and awards, in particular Brett Serviss, coordinator of judging and awards determinations who directed the efforts of judges Mohammed Akhter, Floyd Beckford, Betty Crump, Jim Duke, Maralea Gourley, Joyce Hardin, Shahidul Islam, Salomon Itza, Grover Miller, Jeff Robertson, and Benjamin Rowley.

We gratefully acknowledge the various directors of the science and youth activities which are supported or supervised by the Academy: Betty Crump, Development; Tillman Kennon, Science Education Committee; William Slaton, Arkansas Science Talent Search; Nolan Carter; Junior Academy of Science; Mark Bland, Arkansas Science Fair; and Linda Kondrick, Arkansas Junior Science and Humanities Symposium. We wish to thank all those who served as directors at Regional Science Fairs and Junior Academy Meetings.

We very much appreciate Jeff Robertson for maintaining the Academy website.

We congratulate all who presented papers and posters at this meeting. Student participants are especially recognized since their efforts contribute directly to the future success of the Academy and the improvement and advancement of science in Arkansas. We thank the Arkansas Environmental Federation for supporting the student competition.

The continued success of the Academy is due to its strong leadership. We offer sincere thanks to our officers for another excellent year: Collis Geren (President), Joyce Hardin (President-Elect), Scott Kirkconnell (Vice-President), David Saugey (Immediate Past-President), Stan Trauth (Past-President), Jeff Robertson (Secretary), Mostafa Hemmati (Treasurer), Stan Trauth (Journal Editor-in Chief), Chris McAllister (Journal Managing Editor), Jeff Robertson (Newsletter Editor), and Henry Robison (Historian).

Respectfully submitted this 12th day of April, 2008.

Resolution Committee
Scott Kirkconnell, AAS Vice President
Renn Tumlison, Local Organizing Chair
Jeff Robertson, AAS Secretary

2008-2009 MEMBERSHIP

LIFE MEMBERS

FIRST MI.	LAST NAME	INSTITUTION
Edmond J.	Bacon	University of Arkansas-Monticello
Vernon	Bates	Ouachita Mountains Biological Station
Floyd	Beckford	Lyon College
Wilfred J.	Braithwaite	University of Arkansas-Little Rock
Calvin	Cotton	Geographics Silk Screening Co.
Betty	Crump	Ouachita National Forest
James	Daly	University of Arkansas for Medical Sciences
Mark	Draganjac	Arkansas State University
Jim	Edson	University of Arkansas at Monticello
Daniel R.	England	Southern Arkansas University
Kim	Fifer	University of Arkansas for Medical Sciences
Linda	Gatti-Clark	Hendrix College
Collis	Geren	University of Arkansas-Fayetteville
Anthony	Grafton	Lyon College
Ronald	Javitch	Natural History Rare Book Foundation
Scott	Kirkconnell	Arkansas Tech University
Roger	Koeppe	University of Arkansas-Fayetteville
Roland	McDaniel	FTN Associates
Grover	Miler	University of Arkansas for Medical Sciences
Dennis	Richardson	Quinnipiac College
Jeff	Robertson	Arkansas Tech University
James H.	Fribourgh	University of Arkansas-Little Rock
Arthur	Fry	University of Arkansas-Fayetteville
John	Giese	Ark. Dept. of Env. Qual. (ret)
Walter	Godwin	University of Arkansas-Monticello
Joe M.	Guenter	University of Arkansas at Monticello
Joyce	Hardin	Hendrix College
George	Harp	Arkansas State University
Phoebe	Harp	Arkansas State University
Gary	Heidt	University of Arkansas-Little Rock
Mostafa	Hemmati	Arkansas Tech University
Douglas	James	University of Arkansas-Fayetteville
Arthur	Johnson	Hendrix College
Cindy	Kane	University of Arkansas for Medical Sciences
Donald	Mattison	March of Dimes National Office
Herbert	Monoson	Ark. Science & Technology Authority
James	Peck	University of Arkansas at Little Rock
Michael	Rapp	University of Central Arkansas
Henry	Robison	Southern Arkansas University
David	Saugey	U.S. Forest Service
Stanley	Trauth	Arkansas State University
Gary	Tucker	FTN Associates
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Wayne	Gray	University of Arkansas for Medical Sciences
Roberts	Gregerson	Lyon College
Frank	Hardcastle	Arkansas Tech University
Laurence	Hardy	Ouachita Mountains Biological Station
Philip	Hyatt	retired
Shahidul	Islam	University of Arkansas at Pine Bluff
Salomon	Itza	University of the Ozarks
Clark	Jenkins	North Arkansas College
George	Johnson	Arkansas Tech University
Abul	Kazi	University of Arkansas at Pine Bluff
Brent	Kelley	Audubon Arkansas
Julia	Kennefick	University of Arkansas-Fayetteville
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Jeanne	Kuhler	Auburn University

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Ed	Roberts	Pottsville High School
Fred	Robinson	Ouachita Mtns. Biological Station
Benjamin	Rowley	University of Central Arkansas
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Warren	Montague	USDA/Forest Service
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Dallas	Snider	University of Arkansas-Little Rock
Nickolas	South	University of Arkansas-Little Rock
Jeremy	Stark	University of Arkansas-Little Rock
Katie	Steed	University of Arkansas for Medical Sciences
Shane	Sullivan	University of Arkansas for Medical Sciences
Sharon	Sweeney	University of Arkansas-Little Rock
Allan	Thomas	University of Arkansas-Little Rock
Nathan	Wentz	Arkansas State University

FEATURED GUEST SPEAKER

SHIFTING BASELINES, LOCAL IMPACTS AND GLOBAL CHANGE: WHAT WILL THE OCEANS BE LIKE IN 2025?

Dr. Jeremy Bradford Cook Jackson

Jeremy Jackson is the William E. and Mary B. Ritter Professor of Oceanography and Director of the Center for Marine Biodiversity and Conservation at the Scripps Institution of Oceanography in La Jolla, California. He is also a Senior Scientist Emeritus at the Smithsonian Tropical Research Institute in the Republic of Panama. Dr. Jackson is the author of more than 100 scientific publications and five books. His current research includes the long-term impacts of human activities on the oceans, coral reef ecology and the ecological and evolutionary consequences of the gradual formation of the Isthmus of Panama. Dr. Jackson is a Fellow of the American Academy of Arts and Sciences and the American Association for the Advancement of Science. He is the recipient of numerous prizes and honorary degrees, including the Secretary's Gold Medal for Exeptional Service of the Smithsonian Institution in 1997, the UCSD Chancellor's Award for Excellence in Science and Engineering in 2002 and the International Award for Research in Ecology and Conservatrion Biology of the BBVA Foundation in 2007. Dr. Jackson's work on overfishing was chosen by *Discover* magazine as the outstanding environmental achievement of 2001. He has served on committees and boards of the World Wildlife Fund US, National Research Council, National Center for Ecological Analysis and Synthesis, Yale University Institute of Biospheric Sciences and the Science Commission of the Smithsonian Institution.

This presentation was made possible by generous support from the Matte Lock Ellis College of Arts and Sciences Margin of Excellence Fund, with additional funding from the HSU Undergraduate Research Program and from the HSU Departments of Biology, Chemistry and Physics.

SECTION PROGRAMS

ORAL PRESENTATIONS

(Speakers Underlined)

Session I: Friday 11 April, 1:00 – 2:45 pm

Physics I (Mostafa Hemmati, ATU) REY 127

1:00

DESIGN OF A ROBOTIC ARM FOR PAIN THRESHOLD MEASUREMENTS IN PRE-DIABETIC RATS. Sharon Jones[1], Azida Walker[1] and Maxim Dobretsov[2] . [1] Department of Physics and Astronomy, University of Central Arkansas, Conway, AR, 72034; [2] Department of Anesthesiology, University of Arkansas for Medical Sciences, Little Rock, AR, 72205

1:15

BREAKDOWN WAVES WITH A CURRENT BEHIND THE WAVE FRONT PROPAGATING INTO A NEUTRAL MEDIUM. John King, Sarah Norman and Mostafa Hemmati, Department of Physical Science, Arkansas Tech University, Russellville, AR 72801

1:30

ELECTRON SHOCK WAVES WITH A CURRENT BEHIND THE SHOCK FRONT. Sarah Norman and Mostafa Hemmati; Department of Physical Science, Arkansas Tech University, Russellville, AR 72801

1:45

SYNTHESIS AND CHARACTERIZATION OF HYDROXYAPATITE BIOMATERIALS. Jerakaycia D. Boman,[*] Franklin D. Hardcastle[*+] and Alexandru S. Biris+, *Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801; +University of Arkansas at Little Rock, UALR Center of Nanotechnology, Graduate Institute of Technology, 2801 S. University Ave., Little Rock, Arkansas 72204

2:00

INTEGRATED ELECTRODYNAMIC SCREEN-PHOTOVOLTAIC CELL SYSTEM: A POWER MANAGEMENT APPROACH. Jacob P. Bock, Jason R. Robison, R. Sharma, J. Zhang, M. K. Mazumder; University of Arkansas at Little Rock, 2801 S. University Ave., Little Rock, AR 72204

2:15

CHARACTERIZATION OF SIZE AND CHARGE OF SUB-MICRON PARTICLES. J.W. Stark, M.K. Mazumder, J. Zhang, R. Sharma, and A. J. Adams; University of Arkansas at Little Rock, 2801 S. University Ave., Little Rock, AR 72204

2:30

PHOTOACTIVITY OF TITANIA (TiO_2) NANOTUBES AS WATER SPLITTING CATALYSTS. Ryan J. Snead,[*] Landon B. Hight,[*] Franklin D. Hardcastle,[*+] Rajesh Sharma,[+] and Alexandru S. Biris[+], *Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801
+University of Arkansas at Little Rock, UALR Center of Nanotechnology, Graduate Institute of Technology, 2801 S. University Ave., Little Rock, Arkansas 72204

Chemistry I (Wray Jones, HSU) REY 322

1:00

FURTHER OPTIMIZATION AND CHARACTERIZATION OF CHEMICAL BATH- DEPOSITED OF BISMUTH SULFIDE THIN FILMS. Michael Sattler, Dr. Robert Engelken, Steven Minor, and Matthew Pruitt, Arkansas State University Optoelectronic Materials Research Laboratory, and Environmental Science Graduate Program, P.O. Box 1740, State University, AR 72467

1:15

LIQUID PHASE SULFIDIZATION OF METALS INTO METAL SULFIDES. Matthew Pruitt, Robert Engelken, Michael Sattler, and Paul Minor, College of Engineering and Environmental Sciences Program-Arkansas State University, P.O. Box 1740, State University, AR 72467; Tansel Karabacak and Hye-Won Seo, Department of Applied Science and Department of Physics and Astronomy, University of Arkansas-Little Rock, 2801 S. University Ave., Little Rock, AR 72204

1:30

ORGANIC CHEMICAL BATH DEPOSITION OF INDIUM (III) SULFIDE. Paul Minor*, Robert Engelken, Michael Sattler, and Matthew Pruitt, College of Engineering and Environmental Sciences Program-Arkansas State University; and Tansel Karabacak and Hye-Won Seo, Department of Applied Science and Department of Physics and Astronomy, University of Arkansas-Little Rock

1:45

RAMAN SPECTROSCOPY OF TITANIA (TiO_2) NANOTUBES FOR BIOMEDICAL APPLICATIONS. Landon B. Hight,[*] Ryan J. Snead,[*] Franklin D. Hardcastle,[*+]Rajesh Sharma,[+] and Alexandru S. Biris[+], *Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801
+University of Arkansas at Little Rock, UALR Center of Nanotechnology, Graduate Institute of Technology, 2801 S. University Ave., Little Rock, Arkansas 72204

2:00

DETERMINATION OF CALCIUM AND PHOSPHORUS IN HYDROXYAPATITE BIOMATERIALS USING WET-CHEMICAL ANALYSIS TECHNIQUES. Amanda Stolarz and Franklin D. Hardcastle; Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801

2:15

DETERMINATION OF CALCIUM AND PHOSPHORUS IN HYDROXYAPATITE BIOMATERIALS USING ATOMIC ABSORPTION AND X-RAY FLUORESCENCE SPECTROSCOPIES. Cody Wright and Franklin D. Hardcastle; Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801

2:30

ELECTRON BEAM WRITING OF CRYSTALLINE NANODOTS FOR NEXT GENERATION DEVICES. [1]Benjamin Newton, [1]Dr. Mansour Mortazavi, [2]Dr. Husam Abu-Safe, [2]Dr. Hameed Naseem, [1]University of Arkansas Pine Bluff, Chemistry and Physics Dept, 1200 N. University, Pine Bluff, AR 71601, [2]University of Arkansas Fayetteville , Electrical Engineering Dept. Fayetteville, AR 72701

Biomedicine I (Allen Leible, HSU) REY 120A

1:00

PRODUCT INHIBITION MAY ALTER WARFARIN METABOLISM BY CYP1A2, CYP2C9, AND CYP3A4. Shane Sullivan[1], Ramanagouda RamanagoudrBhojappa[1], Ashley Brown[1], Jeff Moran[2], and Grover P. Miller[1]; [1]Dept of Biochemistry and Molecular Biology; Univ of Ark for Med Sciences Little Rock 72205; [2]Arkansas Department of Health and Human Services, Division of Health Arkansas Public Health Laboratory, Little
Rock, AR 72211

1:15

THE CHRONICITY OF *GIARDIA LAMBLIA* IN ARKANSAS (1988-1997) IN DIFFERENT AGE GROUPS. Bruce A. Dye[1], James N. Pasley[2,] and James J. Daly Sr.[3], Departments of Pharmacology and Toxicology[1], Physiology and Biophysics[2], and Microbiology and Immunology[3] University of Arkansas for Medical Sciences, 4301 W. Markham, Little Rock, AR 72205

1:30
USING MASS SPECTROMETRY TO ELUCIDATE THE STRUCTURE OF BACTERIOPHAGE T4 HELICASE DDA. Lauren P. Blair, Christopher R. Warthen, Alan J. Tackett, and Kevin D Raney, Department of Biochemistry and Molecular Biology, University of Arkansas for Medical Sciences, 4301 W. Markham St., Slot 516, Little Rock, AR 72205

1:45
PROCESSED MRNA, REGULATED BY P38 KINASE AND ATF/CREB PROTEINS, IS REQUIRED FOR HOTSPOT MEIOTIC RECOMBINATION. Jacy L. Wagnon, Mari K. Davidson, and Wayne P. Wahls, Department of Biochemistry and Molecular Biology, University of Arkansas for Medical Sciences, Little Rock, AR 72205

2:00
EPISTATIC ANALYSIS OF THE ROLE OF RNA INTERFERENCE ENZYMES IN HOMOLOGOUS RECOMBINATION. Lindsay M. Bradshaw, Wayne P. Wahls, and Mari K. Davidson, Department of Biochemistry and Molecular Biology, UAMS, Little Rock, AR 72205

2:15
ANGIOGRAPHIC VARIATIONS IN THE CIRCLE OF WILLIS IN THE NEW ZEALAND WHITE RABBIT. C. Brian Caldwell[1], Rene Flores[2], John Lowery[3], and William C. Culp[2], [1]College of Medicine, University of Arkansas for Medical Sciences, Little Rock, AR 72205, [2]Department of Radiology, University of Arkansas for Medical Sciences, Little Rock, AR 72205, [3]Department of Laboratory Animal Medicine, University of Arkansas for Medical Sciences, Little Rock, AR 72205

2:30
THE RELATIONSHIP BETWEEN THE LOCATION OF CHROMOSOMAL BREAKAGE AND THE POSITIONING OF HOMOLOGOUS RECOMBINATION. Katie L. Steed and Mari K. Davidson, Department of Biochemistry and Molecular Biology, UAMS, Little Rock, AR 72205

Botany & Aquat. Biol. (Thomas Smith, SAU) REY 222A

1:00
IDENTIFICATION OF PRICKLE DEVELOPMENT GENES IN *RUBUS* USING A SUBTRACTIVE cDNA LIBRARY. Nathan Jones and J-D Swanson, Department of Biology, University of Central Arkansas, Conway, AR 72035

1:15
GEOGRAPHIC VARIATION IN THE POLLINATION BIOLOGY OF *PASSIFLORA LUTEA* (PASSIFLORACEAE). Janet Lanza and Jennifer Burks Holland, Biology Department, University of Arkansas at Little Rock, 2801 South University, Little Rock, Arkansas 72204

1:30
INVESTIGATING THE LINK BETWEEN TRICHOME AND PRICKLE DEVELOPMENT IN *RUBUS*. Allicia Kellogg and J.D. Swanson, Department of Biology, University of Central Arkansas, Conway AR 72034

1:45
A CONTINUING INVESTIGATION INTO THE OCCURRENCE, ESTABLISHMENT, AND BIOLOGY OF SEVEN, NON–NATIVE, WOODY ANGIOSPERMS IN SOUTHWESTERN ARKANSAS. Nicole Freeman, Allen Leible, Joslyn Hernandez, Chris Talley, Sara Melancen, Johnathan Fuell, Michelle Larsen, and Brett E. Serviss. Department of Biology. Henderson State University. Arkadelphia, AR 71999–0001

2:00
LIMNOLOGICAL ANALYSIS AND TROPHIC CHARACTERIZATION OF LAKE GREESON, ARKANSAS. Alan D. Christian, Allison M. Asher, Kevin A. Keen, and Justin L. Ward, Arkansas State University, Department of Biological Sciences, P.O. Box 599, State University, Arkansas 72467

2:15
A PRELIMINARY REPORT ON THE ALGAE FROM AGRICULTURAL FIELD IN ST. FRANCIS COUNTY, ARKANSAS. Thomas Smith, Southern Arkansas University, Dept. of Biology, Magnolia, AR 71753

2:30
EVALUATION OF MOISTURE CONTENT AND SPECIFIC GRAVITY VALUES OF PLANTATION GROWN EASTERN COTTONWOOD (*POPULUS DELTOIDES* BARTR.). Jonathan I. Hartley and David W. Patterson, Arkansas Forest Resources Center, University of Arkansas-Monticello School of Forest Resources, Monticello, AR 71656

Session II: Friday 11 April, 3:00 – 4:15 pm

Physics II (Jeff Robertson, ATU) REY 127

3:00
COMPUTER SIMULATION OF ELECTRODYNAMIC SCREENS. Jason R. Robison, R. Sharma, J. Zhang, M. K. Mazumder; University of Arkansas at Little Rock
2801 S. University Ave., Little Rock, AR 72204

3:15
BALLOONSAT AND LABPRO: HIGH ALTITUDE BALLOON EXPERIMENTS FOR HIGH SCHOOL STUDENTS. Kim Mason and William V. Slaton, Department of Physics and Astronomy, University of Central Arkansas, 201 Donaghey Ave., Conway, AR 72035

3:30
LI DOPED ZnO NANOWIRES GROWN BY A LOW TEMPERATURE ELECTROCHEMICAL PROCESS. Allan Thomas[1], Yuchoong Soo[1], and Jingbiao Cui[1], [1]Department of Physics and Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204

3:45
THE TRANSFER FUNCTION AND SENSOR CALIBRATION. Gregory W. Lyons, Harding Box 12323 Searcy, AR 72149-2323

4:00
USLI 2008 HARDING FLYING BISON ROCKET COMPETITION. Paul R. Elliott, Harding Box 11462 Searcy, AR 72149-1462

Chemistry II (Janice O'Donnell, HSU) REY 322

3:00
A SYNTHETIC AND SPECTROSCOPIC INVESTIGATION OF THE THIOSEMICARBAZONE FROM *p*-DIMETHYLAMINOBENZALDEHYDE. Floyd Beckford, Christopher Robertson and Ryan Harness; Lyon College, 2300 Highland Road, Batesville, AR 72501

3:15
TDLAS OF METHANE ISOTOPOMERS. Sarah E. Christensen, Harding Box 11164, Searcy, AR 72149-1164

3:30
THE STRUCTURE OF PHOSPHATE SPECIES IN CALCIUM PHOSPHATE BIOMATERIALS BY RAMAN SPECTROSCOPY. Franklin D. Hardcastle , Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801; University of Arkansas at Little Rock, UALR Center of Nanotechnology, Graduate Institute of Technology, 2801 S. University Ave., Little Rock, Arkansas 72204

3:45
RADICAL SCAVENGING ACTIVITIES OF CAFFEOYLQUINIC ACID DERIVATIVES FROM LEAVES OF SWEETPOTATO. Joseph C. Onyilagha and Shahidul Islam, Department of Agriculture, University of Arkansas at Pine Bluff, 1200 North University Drive, Mail Slot 4913, Pine Bluff, AR 71601

4:00
DOES NICOTINE INHIBIT ANTI-SPORE MECHANISM ACHIEVED BY GYLCOCONJUGATES. J.Parsons, J. Castleberry, and O. Tarasenko, Department of Biology, University of Arkansas at Little Rock

Vert. Zool. & Environ. Sci. (Chris Guyer, HSU) REY 120A

3:00
EFFECTS OF INDIGENOUS COMMUNITIES AND AGRICULTURE ON CORAL REEF COMPOSITION IN THE WESTERN GULF OF SAN BLAS, PANAMA. [1]April Helms, [2]Michelle Dare, [3]Shara Jones, and [1]James Engman. [1]Henderson State University Biology Department, P.O. Box 7520, Arkadelphia, AR 71999-0001; [2]University of New Hampshire, Department of Plant Biology, 38 College Road, Spaulding Hall G28, Durham, NH 03824; [3]Lewis and Clark Law School, 10015 Southwest Terwilliger Blvd., Portland, OR 97219

3:15
ACCURACY ASSESSMENT OF RECREATIONAL AND MAPPING GRADE GPS UNITS IN THREE DIFFERENT LANDSCAPES. Michael Gilbert, Jack Cross, and Robert C. Weih, Jr., School of Forestry Resources, Spatial Analysis Laboratory, University of Arkansas-Monticello, 110 University Court, Monticello, Arkansas 71656

3:30
CRETACEOUS SHARKS OF SOUTHWEST ARKANSAS. Jerred Caskey, Dr. Leo C. Davis, Dr. Henry Robison, Dr. Thomas Smith, Department of Geology, Department of Biology, Southern Arkansas University, 100 East University, Magnolia, AR, 71754

3:45
SMALL MAMMAL COMMUNITY DYNAMICS ON A WETLAND RESTORATION SITE IN SOUTHEASTER ARKANSAS. Tiffany A. Whitsitt and Philip A. Tappe, Arkansas Forest Resources Center & School of Forest Resources, University of Arkansas at Monticello, 110 University Ct., Monticello, AR 71656

4:00
MUSSEL INVENTORY AND POPULATION STATUS OF THE FEDERALLY ENDANGERED *POTAMILUS CAPAX* (GREEN 1832) IN THE TYRONZA RIVER, ARKANSAS. Nathan J. Wentz[1], John L. Harris[1], Jerry L. Farris[2], and Alan Christian[1, 2] Arkansas State University, [1]Department of Biological Sciences, PO Box 599, State University, AR 72467, [2]Environmental Sciences Program, PO Box 877, State University, AR 72467

Botany II (J.D. Swanson, UCA) REY 222A

3:00
A COMPARISON OF PINE HEIGHT MODELS FOR THE CROSSETT EXPERIMENTAL FOREST. Don C. Bragg, Southern Research Station, USDA Forest Service, P.O. Box 3516 UAM, Monticello, AR 71656

3:15
MANAGEMENT OF INVASIVE PLANTS ON TWO NATURAL AREAS IN SOUTHWEST ARKANSAS. Tobin Fulmer, Arkansas Natural Heritage Commission, 1500 Tower Building, 323 Center street, Little Rock, AR, 72201

3:30
AN EXPERIMENTAL TEST OF THE ROLE OF MORPHOLOGICAL PLASTICITY ON INVASIVENESS IN LONICERA VINES. Katherine Larson, Department of Biology, University of Central Arkansas, Conway, AR 72035

3:45
PITFALLS ASSOCIATED WITH ESTABLISHING SHORT ROTATION BIOFUEL PLANTATIONS. Jamie L. Schuler, Matthew Pelkki, and Chris Stuhlinger, University of Arkansas-Monticello, Monticello, AR 71656

Session III: Saturday 12 April, 8:00 – 9:15 am

Physics III (Daniel Bullock, ATU) REY 127

8:00
MULTI-WAVELENGTH REFLECTANCE AND TRANSMISSION STUDIES IN TURBID MEDIA. Al Adams and Michael Fahrenwald, Department of Physics and Astronomy, University of Arkansas at Little Rock, 2801 S. University Ave, Little Rock, AR 72204-1099

8:15
NEW ECLIPSING VARIABLE DISCOVERED IN SEXTANTS. Jeff W. Robertson, George Roberts, R. Tut Campbell, Arkansas Tech University, Department of Physical Sciences, 1701 N. Boulder, Russellville, AR 72801-2222

8:30
ON THE APPLICATION OF IMPROVEMENTS FOR PRONY'S METHOD OF SYSTEM IDENTIFICATION IN SIGNAL PROCESSING. Chih-Hao Wu, Department of Electrical Engineering, Arkansas Tech University, 1815 Coliseum Drive, Russellville, AR 72801

8:45
EPITAXIALLY GROWN QUANTUM DOTS FOR SOLAR CELL APPLICATIONS. Shane Hendrix and Daniel Bullock, Department of Physical Science, Arkansas Tech University, Russellville, AR

9:00
TAKING ANOTHER LOOK: LIGHT N-CAPTURE ELEMENT ABUNDANCES IN METAL-POOR HALO STARS. Debra L. Burris, E. Marilea Jones and Jeremy Lusk, Department of Physics and Astronomy, University of Central Arkansas, 72035

Chemistry III (Brett Serviss, HSU) REY 322

8:00
SPECTRAL LINESHAPES FOR METHANE. Kyle E. Arthur, Harding Box 12562, Searcy, AR 72149-2562

8:15
SPECTROSCOPY OF COMBUSTION PROCESSES. Megan N. Bush, Harding Box 11348, Searcy, AR 72149-1348

8:30
DIODE LASER MAPPING OF WATER IN BIOLOGICAL SPECIMENS. Erin E. Fulks, Harding Box 12036, Searcy, AR 72149-2036

8:45
A VERSATILE MINI ROCKET TEST STAND. Aaron W. Howell, Harding Box 13581, Searcy, AR 72149-3581

9:00
SPECTROSCOPY USING A HERRIOTT CELL. Gregory W. Lyons, Harding Box 12323, Searcy, AR 72149-2323

Invertebrate Zoology I (Troy Bray, HSU) REY 120A

8:00
DISTRIBUTION AND TAXONOMIC STATUS OF TARANTULAS IN ARKANSAS (THERAPHOSIDAE: APHONOPLEMA). Michael D. Warriner, Arkansas Natural Heritage Commission, 1500 Tower Building, 323 Center Street, Little Rock, AR 72201

8:15
NEW ANT DISTRIBUTIONAL RECORDS FOR ARKANSAS. David M. General and Lynne C. Thompson, School of Forest Resources, Arkansas Forest Resources Center, 100 University Court, University of Arkansas at Monticello AR 71656

8:30
INSECTS INHABITING THE BURROWS OF THE OZARK POCKET GOPHER IN ARKANSAS. Peter Kovarik[1], Stephen W.

Chordas III[2], Gary A. Heidt[3], Henry W. Robison[4], Matthew B. Connior[5], Justin G. Fiene[5], and Paul E. Skelley[6]. [1]Columbus State Community College, 239 Crestview Road, Columbus, Ohio 43202. [2]CLSE, Ohio State University, 1735 Neil Avenue, Columbus Ohio 43210; [3]Department of Biology, University of Arkansas Little Rock, 2801 S. University, Little Rock, Arkansas 72204; [4]Department of Biology, Southern Arkansas University, Magnolia, Arkansas 71754; [5]Department of Biological Sciences, Arkansas State University, State University, Arkansas 72467; [6]Florida State Collection of Arthropods, 1911 SW 34th St., P.O. Box 147100, Gainesville, Florida 32614.

8:45
FOUR NEW STATE RECORDS OF TERRESTRIAL HEMIPTERA (2 COREIDAE; 2 LYGAEOIDEA) FOR ARKANSAS. Stephen W. Chordas III[1] and Peter Kovarik[2], [1]Center for Life Sciences Education, The Ohio State University, 260 Jennings hall, 1735 Neil Avenue, Columbus Ohio 43210; [2]Columbus State Community College, 239 Crestview Road, Columbus Ohio 43202.

9:00
AQUATIC MACROINVERTEBRATES OF 41 MISSOURI OZARK STREAMS. George L. Harp and Phoebe A. Harp, Dept. of Biological Sciences, Arkansas State University, State University, AR 72467

Vertebrate Zoology II (Bill Shepherd, Audubon Arkansas) REY 222A

8:00
THE ARKANSAS ENDEMIC BIOTA: AN UPDATE WITH ADDITIONS AND DELETIONS. [1]Henry W. Robison, [2]Chris T. McAllister, [3]Christopher Carlton, and [4]Gary Tucker. [1]Department of Biology, Southern Arkansas University, Magnolia AR 71754; [2]Department of Biology, Chadron State College, Chadron, NE 69337; [3]Department of Entomology, Louisiana State University, Baton Rouge, LA 70803; and [4]Gary Tucker, FTN Associates, Ltd., 3 Innwood Circle, Suite 220, Little Rock, AR 72211

8:15
INVENTORY OF AMPHIBIAN, REPTILE, AND SMALL MAMMAL ASSOCIATES OF OZARK POCKET GOPHER HABITAT IN IZARD COUNTY, ARKANSAS. Matthew B. Connior, Idun Guenther, Thomas S. Risch, and Stanley E. Trauth, Department of Biological Sciences, Arkansas State University, PO Box 599, State University, AR 72467

8:30
FISHES OF RED RIVER OXBOW LAKES IN ARKANSAS. Thomas M. Buchanan, Department of Biology, University of Arkansas – Fort Smith, Fort Smith, AR 72913, Drew Wilson and L.G. Claybrook, Arkansas Game & Fish Commission, 2 Natural Resources Drive, Little Rock, AR 72205

8:45
THE POPULATION GENETICS OF STARGAZING DARTER IN ARKANSAS II: SURVEYING POPULATIONS. Tsunemi Yamashita, Department of Biological Sciences, Arkansas Tech University, Russellville, AR 72801

9:00
RABIES IN ARKANSAS BATS, 1983-2007. D. Blake Sasse[1] and David A. Saguey[2]. [1]Arkansas Game and Fish Commission, #2 Natural Resources Drive, Little Rock, AR 72205; [2] U.S. Forest Service, P.O. Box 189, Jessieville, AR 71949

Session IV: Saturday 12 April, 9:30 – 11:00 am

Biomedicine II (Charles Wu, ATU) REY 127

9:30
THE EFFECT OF FRACTIONS OF HUMAN SEMEN ON STIMULATION AND INHIBITION ON THE GROWTH OF *TRICHOMONAS VAGINALIS*. James J. Daly Sr. and Jerome K. Sherman, Departments of Microbiology and Immunology and Neurobiology and Developmental Sciences, University of Arkansas for Health Sciences, 4301 W. Markham, Little Rock , AR 72205

9:45
IDENTIFYING ROLE OF RING SUBSTITUENTS ON MOLECULAR BINDING AND STOICHIOMETRY FOR CYP2E1 COMPLEXES. Ryan M. Laddusaw[1], Daniel Judkins[2], Martin D. Perry, Jr[2], and Grover P. Miller[1], [1]Dept of Biochemistry and Molecular Biology, Univ. of Ark for Med Sciences, Little Rock 72205; [2]Department of Chemistry, Ouachita Baptist University, Arkadelphia, AR 71998

10:00
PREVALENCE OF *STAPHYLOCOCCUS AUREUS* AMONG NURSING AND ALLIED HEALTH STUDENTS. David F Gilmore, William Wilson, Jennifer Little, Candy Lincoln, and Lauren Ford, PO Box 599, Dept. of Biological Sciences, Arkansas State University, State University, AR 72467

10:15
KNOWLEDGE DISCOVERY WITHIN FETAL ACTIVITY DATA. [1]Dallas. H. Snider, [2]Xiaowei Xu, and [3]Rathinaswamy B. Govindan. [1]University of Arkansas – Little Rock, Department of Applied Science, 2801 S. University – ETAS 575, Little Rock, AR 72204; [2]University of Arkansas – Little Rock, Department of Information Science, 2801 S. University – ETAS 258, Little Rock, AR 72204; [3]University of Arkansas for Medical Sciences, Department of Obstetrics and Gynecology, 4301 W. Markham, Little Rock, AR 72205

10:30
A COMPUTATIONAL BIOLOGY APPROACH TO FULL BREAST MATHEMATICAL MODELING. Jordan Greenlee and Magda El-Shenawee, University of Arkansas, Department of Electrical Engineering, 3217 Bell Engineering Center, Fayetteville, AR 72701

10:45
EXPRESSION AND LOCALIZATION OF MULTIPLE INOSITOL POLYPHOSPHATE PHOSPHATASE DURING APOPTOSIS. Samea Lone, Rahkee Agarwal, and Nawab Ali, PhD, Graduate Institute of Technology University of Arkansas at Little Rock, 2801 S. University Avenue, Little Rock, AR 72204

Science Potpourri (Anwar Bhuiyan, ATU) REY 322

9:30
AN AUTOMATED ATMOSPHERIC KINETICS APPARATUS. Christopher S. Smeal, Harding Box 12926, Searcy, AR 72149-2926

9:45
RAMAN SPECTROMETER. Stephen D. Wagner, Harding Box 11412 Searcy, AR 72149-1412

10:00
PROFILES ON THE FEMININE BURST INTO SCIENCE. Kristen K. Irwin, Undergraduate Student, Department of Biological Sciences Arkansas State University, P.O. Box 599, State University, 72467

10:15
COLLEGE STUDENTS' OPINIONS OF ENGAGING APPROACHES IN A PHYSICAL SCIENCE COURSE. Dr. Wilson J. González-Espada, Department of Physical Science, Arkansas Tech University, 1701 North Boulder Avenue, Russellville, AR 72801

10:30
PROLINE INCREASES THE THERMODYNAMIC STABILITY OF PROTEINS. Andrew Avery, D. Rajalingam Ph.D. and T.K.S. Kumar Ph.D., Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701

10:45
BENEFITS OF LEED DESIGNS IN ARKANSAS K-12 SCHOOLS. Philip Thrift and Darin Nutter, Dept. of Mechanical Engineering, Universtiy of Arkansas, Fayetteville, AR 72701

Invertebrate Zoology II (Henry Robison, SAU) REY 120A

9:30

***EIMERIA WENRICHI* (APICOMPLEXA: EIMERIIDAE) FROM THE WOODLAND VOLE, *MICROTUS PINETORUM* (RODENTIA: CRICETIDAE), FROM CENTRAL ARKANSAS: A NEW HOST AND GEOGRAPHIC RECORD.** [1]Chris T. McAllister, [2]Robert S. Seville, and [3]Steve J. Upton. [1]Department of Physical and Life Sciences, Chadron State College, Chadron, NE 69337; [2]Department of Zoology and Physiology, University of Wyoming/Casper Center, Casper, WY 82601; and [3]Department of Biology, Ackert Hall, Kansas State University, Manhattan, KS 66506

9:45

A NEW STATE RECORD FOR *EURYMERODESMUS MUNDUS* CHAMBERLIN (DIPLOPODA: POLYDESMIDA: EURYMERODESMIDAE), FROM LOUISIANA, WITH NOTEWORTHY RECORDS OF EURYMERODESMID MILLIPEDS IN ARKANSAS, KANSAS, LOUISIANA, OKLAHOMA, AND TEXAS. [1]Chris T. McAllister and [2]Rowland M. Shelley. [1]Department of Physical and Life Sciences, Chadron State College, Chadron, NE 69337; and [2]Research Lab, North Carolina Museum of Natural Sciences, 4301 Reedy Creek Road, Raleigh, NC 27607

10:00

ACANTHOCEPHALAN PARASITES (ECHINORHYNCIDA: HETERACANTHOCEPHALIDAE; POMPHORHYNCHIDAE) FROM THE PIRATE PERCH (PERCOPSIFORMES: APHREDODERIDAE), FROM THE CADDO RIVER, ARKANSAS. [1]Chris T. McAllister and [2]Omar Amin. [1]Department of Physical and Life Sciences, Chadron State College, Chadron, NE 69337; and [2]Institute of Parasitic Diseases, P. O. Box 28372, Tempe, AZ 85285

10:15

TEACHING A PLATYHELMINTH (*BIPALIUM KEWENSE*) NEW TRICKS. James J. Daly Sr.[1], Bruce White[1], and H. Michael Matthews[2], [1]Department of Microbiology and Immunology, University of Arkansas for Medical Sciences, 4301 W. Markham, Little Rock Arkansas 72205, and [2]Department of Biology, Henderson State University, 1100 Henderson St., Arkadelphia, Arkansas 71999

POSTER PRESENTATIONS

***BIOLOGY POSTERS* (alphabetized by first author)**

DETERMINATION OF FTSZ'S ROLE IN MITOCHONDRIAL FISSION. Brittany Carson, Amanda Jones, and Dr. Kari Naylor, Department of Biology, University of Central Arkansas, Conway, AR 72035

FREE RADICAL SCAVENGING PROPERTIES OF PLANT POLYPHENOLS. Xi Chen, Johnmesha Sanders, Sarah Crutchfield, and Stephen Grace, Ph.D., Department of Biology, University of Arkansas at Little Rock, Department of Chemistry and Physics, University of Arkansas at Pine Bluff

ANTIBODY HEAVY CHAIN V(D)J REARRANGEMENTS IN MERCURY-TREATED VS. CONTROL A.SW MICE. Heather J. Clarke, Britne Kuykendall, and Ben Rowley, Department of Biology, University of Central Arkansas, Conway, AR 72035.

SURVEY OF THE SHORE AND AQUATIC VASCULAR FLORA OF THE BIG MAUMELLE RIVER DOWNSTREAM OF LAKE MAUMELLE, PULASKI COUNTY, ARKANSAS. Douglas N. Dawson, Rebecca Fry, Nickolas V. South, Margaret E. McMillan, Forest E. Payne, and James H. Peck, Department of Earth Science and Department of Biology, University of Arkansas, 2801 S. University Ave., Little Rock, AR 72204.

CYP2E1 OVEREXPRESSION INHIBITS SERCA ACTIVITY IN HEPG2 CELLS. Kerry L. Evans and Andres A. Caro, Ph.D., Chemistry Department, Hendrix College, Hendrix College, Conway, AR 72032

EFFECTS OF SCHEDULED BURNING IN CONTROL OF COMPETITION BETWEEN NATIVE AND INVASIVE HONEYSUCKLE IN ARKANSAS. Benjamin Frizzell and Katherine Larson, Department of Biology, University of Central Arkansas, Conway, AR 72035

SURVEY OF THE SHORE AND AQUATIC VASCULAR FLORA OF THE BIG MAUMELLE RIVER UPSTREAM OF LAKE MAUMELLE, PULASKI COUNTY, ARKANSAS. Rebecca L. Fry, Douglas N. Dawson, Nickolas V. South, Margaret E. McMillan, Forrest E. Payne, and James H. Peck, Department of Earth Sciences and Department of Biology, University of Arkansas at Little Rock, 2801 S. University Ave., Little Rock, AR 72204

ANTS OF ARKANSAS POST NATIONAL MEMORIAL: HOW AND WHERE COLLECTED. David M. General and Lynne C. Thompson, Arkansas Forest Resources Center, School of Forest Resources, University of Arkansas- Monticello, Monticello, AR 71656-3468

CREATING TOOLS TO STUDY IMMUNITY IN *CANDIDA ALBICANS*. Wes Greer, Department of Biological Sciences, University of Arkansas, Fayetteville, Ar 72701

DETERMINING CAF4'S FUNCTION IN *SACCHAROMYCES CEREVISIAE*. Matt Harvison, Jacob Seiter, and Dr. Kari Naylor, Department of Biology, University of Central Arkansas, Conway AR, 72035

THE INFLUENCE OF HEAT ACTIVATION OF *BACILLUS* SPORES DURING POST-PHAGOCYTOSIS STUDIES. Kristin Hester, and Olga Tarasenko, M.D., Ph.D.; Department of Biology, University of Arkansas Little Rock, Little Rock, Arkansas

SCATTER-CACHING BEHAVIOR IN EASTERN GRAY SQUIRRELS (*SCIURIS CAROLINENSIS*). Lucy Holifield and Dr. Jennifer Penner, Department of Psychology, Hendrix College, Conway, AR 72032

THE EFFECT AGE AND SEX ON VISUAL REACTION TIMES. Hutson, C. and T. Smith, Southern Arkansas University, Dept. of Biology, Magnolia, AR 71753

RELATIONSHIPS BETWEEN GROUNDWATER LEVEL AND FURBEARER ABUNDANCE IN THE NORTHERN ARKANSAS MISSISSIPPI ALLUVIAL VALLEY. John Kidd and Robert E. Kissell, Jr., Arkansas Forest Resources Center, School of Forest Resources, University of Arkansas-Monticello, Monticello, AR 71656

UTILIZING MOLECULAR MARKERS TO ESTABLISH THE GENETIC RELATEDNESS WITHIN SELECTED FAMILIES AND GENOTYPES OF BLACKBERRY PLANTS. Nicole Knox, Madeline Richmond, and JD Swanson, Department of Biology, University of Central Arkansas, Conway, AR 72035

ANTIBACTERIAL PROPERTIES OF SPICES. Koroney, A. and T. Smith, Southern Arkansas University, Dept. of Biology, Magnolia, AR 71753

DENDROCHRONOLOGY ANALYSIS OF THE RED RIVER IN SOUTHWEST ARKANSAS. Rebecca Lewis, Leo Carson Davis, Department of Biology and Department of Geology, Southern Arkansas University, 100 East University , Magnolia, AR 71753

A PILOT *IN VIVO* STUDY OF IMMUNE RESPONSES TO A NOVEL NICKEL-BASED ANTI-TUMOR COMPOUND IN MERCURY SUSCEPTIBLE A.SW MICE. J. Leigh Methvin, D. Brett Rabeneck, Patrick J. Desrochers, and Ben Rowley, Department of Biology, University of Central Arkansas, Conway, AR 72035

STUDY OF HUMAN MACROPHAGE VIABILITY DURING GLYCOCONJUGATE-ENHANCED PHAGOCYTOSIS OF *BACILLUS CEREUS* SPORES. Ashley Scott, and Olga Tarasenko, M.D., Ph.D. Department of Biology, University of Arkansas at Little Rock, Little Rock, Arkansas

SURVEY OF THE SHORE AND AQUATIC VASCULAR FLORA OF THE LITTLE MAUMELLE RIVER DOWNSTREAM FROM PINNACLE MOUNTAIN TO THE ARKANSAS RIVER, PULASKI COUNTY, ARKANSAS. Nickolas V. South, Rebecca L. Fry, Douglas N. Dawson, Margaret E. McMillan, Forrest E. Payne, and James H. Peck, Department of Earth Science and Department of Biology, University of Arkansas at Little Rock, 2801 S. University Ave., Little Rock, AR 72204.

MACROPHYTE SURVEY OF THE SHORE AND AQUATIC VASCULAR FLORA OF LAKE MAUMELLE, PULASKI COUNTY, ARKANSAS. Sharon M. Sweeney, Nickolas V. South, Christopher J. Schaller, Jeremy P. Reese, Philip A. James, Mitchell G. Burroughs, Margaret E. McMillan, Forrest E. Payne, and James H. Peck, Department of Earth Science and Department of Biology, University of Arkansas at Little Rock, 2801 S. University Ave., Little Rock, AR 72204.

OXIDATION OF BIOMOLECULES IN MICROSOMES DERIVED FROM CYP2E1-OVEREXPRESSING HEPG2 CELLS. Joe Thomas and Andres A. Caro, Ph.D., Chemistry Department, Hendrix College

TERRITORIALITY OF MALE SWAMP RABBITS (*SYLVILAGUS AQUATICUS*) IN SOUTHEASTERN ARKANSAS. Karen B. Vale and Robert E. Kissell, Jr., Arkansas Forest Resources Center, School of Forest Resources, University of Arkansas-Monticello, Monticello, AR 71656

COMPATIBLE STEM TAPER AND TOTAL TREE VOLUME EQUATIONS FOR LOBLOLLY PINE (*PINUS TAEDA* L.) PLANTATIONS IN SOUTHEASTERN ARKANSAS. Curtis L. VanderSchaaf, Arkansas Forest Resources Center, University of Arkansas at Monticello, Monticello, AR 71656

RETINOBLASTOMA FAMILY MEMBER P107 IN ADIPOCYTE DIFFERENTIATION. Michael Wainscott, Tyler Sanford and Timothy E. Hayes, Ph.D., Depts. of Biology and Chemistry, Ouachita Baptist University

LAND-COVER CHARACTERIZATION USING AN OBJECT-BASED CLASSIFIER FOR THE BUFFALO RIVER SUB-BASIN IN NORTH-CENTRAL ARKANSAS. Robert C. Weih, Jr. and Don White, Jr., Spatial Analysis Laboratory (SAL), University of Arkansas at Monticello (UAM) Arkansas Forest Resources Center, School of Forest Resources, 110 University Court, Monticello, Arkansas 71656

HISTORICAL FOREST LANDSCAPE CHANGES IN THE BUFFALO RIVER SUB-BASIN IN ARKANSAS. Robert C. Weih, Jr.[1] and Aaron J. Dick[2], [1]Spatial Analysis Laboratory (SAL), University of Arkansas at Monticello, Arkansas Forest Resources Center, School of Forest Resources, 110 University Court, Monticello, Arkansas 71656; [2]Bureau of Land Management 4621 East 65th Avenue Lower, Spokane, WA 99223

CAF4'S ROLE IN MITOCHONDRIAL FISSION EVENTS. Emily Woods, Justin Allen, and Dr. Kari Naylor, Department of Biology, University of Central Arkansas, Conway, 72035

***CHEMISTRY POSTERS* (alphabetized by first author)**

NOVEL THIOSEMICARBAZONES FROM 9-ANTHRALDEHYDE AND THEIR COPPER AND RUTHENIUM COMPLEXES. Floyd Beckford and Gabriel Leblanc, Lyon College, 2300 Highland Road, Batesville, AR 72501

INTER- AND INTRAMOLECULAR KETENE-NITRILE OXIDE CYCLOADDITIONS. Mack Clements and Jay P. Deville, PhD, Department of Chemistry, Henderson State University, 1100 Henderson St., Arkadelphia, AR 71999-0001

A SURVEY OF GROUND LEVEL RADON IN A TWO COUNTY AREA. Heather Collier and Bryan D. Palmer, Ph.D., Department of Chemistry, Henderson State University, Arkadelphia AR 71999

PREPARATION OF FUNCTIONALIZED NANOTUBES FOR INVERSE GAS CHROMATOGRAPHIC ANALYSIS. Lisa K. Cortez, Chad B. R. Seevers, John R. Hardee, Ph.D. and Jay P. Deville, Department of Chemistry, Henderson State University, 1100 Henderson St., Arkadelphia, AR 71999-0001

REACTIVE INTERMEDIATES IN DIELS-ALDER CYCLOADDITIONS. Kitior Fofung and Jay P. Deville, Department of Chemistry, Henderson State University, 1100 Henderson St., Arkadelphia, AR 71999-0001

SYNTHESIS AND BIOLOGICAL ACTIVITY OF THYMOL DERIVATIVES. Michael Haltom, Rebecca Staton, Christopher Guyer, and Jay P. Deville, Department of Chemistry, Henderson State University, 1100 Henderson St., Arkadelphia, AR 71999-0001

AN INVESTIGATION OF SCANDIUM, STRONTIUM, AND ALUMINUM SUBSTITUTIONS IN YBCO TYPE SUPERCONDUCTORS. Benjamin Hornbeck and Bryan D. Palmer Ph.D., Department of Chemistry, Henderson State University, 1100 Henderson St., Arkadelphia, AR 71999-0001

SYNTHESIS OF HIGHLY SUBSTITUTED ALLYLIC ALCOHOLS AND ESTERS. Ryne Johnston and Martin J. Campbell, Ph.D, Department of Chemistry, Henderson State University, 1100 Henderson St., Arkadelphia, AR 71999-0001

ETHYLGLUCURONIDE (EtG) ASSESSED BY TWO METHODS FOLLOWING FRAGRANCE AND HAND SANITIZER EXPOSURE IN MEN AND WOMEN. Julie Kissack, Harding University, College of Pharmacy, Searcy, AR 72149

AN INVESTIGATION OF BARIUM OXIDE REPLACEMENT IN YBCO TYPE SUPERCONDUCTORS. Luke S. McCage and Bryan D. Palmer, Ph.D., Department of Chemistry, Henderson State University, Arkadelphia AR 71999

EXAMINATIONS INTO THE UTILITY OF THE ACYCLIC ALLYLIC DIAZENE REARRANGEMENT. Blake Williams, Matt McIntosh, and Wei Qi. University of Arkansas-Fayetteville Department of Chemistry and Biochemistry. 119 Chemistry Building, Fayetteville, AR 72701.

***PHYSICS POSTERS* (alphabetized by first author)**

RESONANCE RAMAN SPECTROSCOPY FOR THE INVESTIGATION OF HETEROLEPTIC RUTHENIUM POLYPYRIDINE COMPLEXES. Anwar A. Bhuiyan, Department of Physical Sciences, Arkansas Tech University, Russellville, AR 72801

THICKNESS DETERMINATION USING RUTHERFORD BACKSCATTERING OF ALPHA-PARTICLES. Russell Cline, Brian Halldorson, and Rahul Mehta, Department of Physics and Astronomy, Lewis Science Center 171, University of Central Arkansas, 201 Donaghey Avenue, Conway, AR 72035

HYBRID ROCKET RESTART CAPABILITIES. Joseph Gracy and Larry Roe, Ph.D., Mechanical Engineering Department, University of Arkansas-Fayetteville

DESIGN AND IMPLEMENTATION OF A DIGITAL ACCELOROMETER. Shane Hendrix and Daniel Bullock, Department of Physical Science, Arkansas Tech University, Russellville, AR

APPLICATIONS OF DIGITAL SIGNAL CONTROLLER IN SUBMICRON POSITION CONTROL OF A LINEAR MOTOR. Coletha Johnson and Jing Zhang, Systems Engineering Department, University of Arkansas at Little Rock, Little Rock, AR 72204

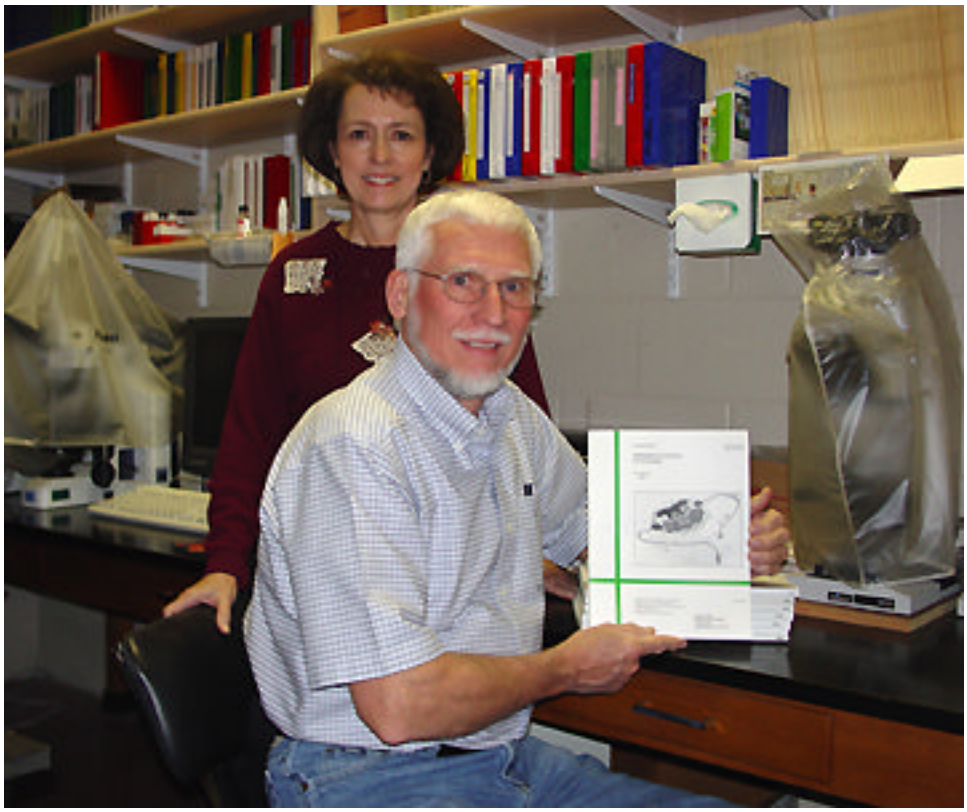
ERROR ANALYSIS OF N-CAPTURE ELEMENT ABUNDANCE IN HALO GIANTS. E. Marilea Jones and Debra L. Burris, Department of Physics and Astronomy, University of Central Arkansas, Conway, 72035

PIXE AND RUTHERFORD SCATTERING OF ALPHA PARTICLES. Patrick Kells, Nathan Walsh, and Rahul Mehta Department of Physics and Astronomy, Lewis Science Center 171, University of Central Arkansas, 201 Donaghey Avenue, Conway, AR 72035

GAMMA RAY SPECTROSCOPY: DETERMINING HALF-LIVES AND ABSORPTION COEFFICIENTS. Michael C. Kitchens and Rahul Mehta ,Department of Physics and Astronomy, Lewis Science Center 171, University of Central Arkansas, 201 Donaghey Avenue, Conway, AR 72035

A COMPARISON OF THE LIGHT N-CAPTURE ELEMENTS TO BARIUM IN HALO STARS. Jeremy Lusk and Debra L. Burris, University of Central Arkansas, Dept. of Physics and Astronomy, Conway, AR 72035

A TRIBUTE TO DRs. STAN AND JOY TRAUTH



As stated in the constitution, the objectives of the Arkansas Academy of Science are "the promotion and diffusion of the fields of Science and unification of these interests in the State". The organization strives to achieve these objectives primarily through the annual meeting and publication of the journal. The Journal of the Arkansas Academy of Science serves as the major conduit through which scientific information is actually shared with the rest of the world. This publication is shared with libraries and researchers across the world in paper and electronic form.

That the Journal of the Arkansas Academy of Science is recognized as one of the top publications of state academies of science is in large part due to the hard work and dedication of Drs. Stan and Joy Trauth. Dr. Stan Trauth resumed the duties of the editor in 1992 and served three terms as either the solo editor or the editor in chief. During this long service, he made significant changes to enhance the quality of the journal. Building on the work of previous editors, under Stan's stewardship the publication shifted from being a proceeding of the annual meeting to a referred journal. The format of the publication changed to reflect the changing look of scientific publications.

We also owe a debt of gratitude to Dr. Joy Trauth. During the 15 years that Stan served as the editor, Joy read every manuscript for format, style, and some content. That amounts to a staggering 500 manuscripts! When reflecting upon his duties as the editor, Stan will quickly tell you that "I couldn't have managed all of those years without her help!"

We dedicate this volume of the Journal to Drs. Stan and Joy Trauth to honor their distinguished and dedicated service to the Arkansas Academy of Science.

A Comparison of Pine Height Models for the Crossett Experimental Forest

D. Bragg

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Abstract

Many models to predict tree height from diameter have been developed, but not all are equally useful. This study compared a set of height-diameter models for loblolly (*Pinus taeda*) and shortleaf (*Pinus echinata*) pines from Ashley County, Arkansas. Almost 560 trees ranging in diameter at breast height (DBH) from 0.3 cm (both species) to 91.9 cm (for shortleaf) or 108.2 cm (for loblolly) were chosen for measurement. Height equations were then fit to four different functions (Chapman-Richards, modified logistic, exponential, and Curtis-Arney) with weighted nonlinear least squares regression using DBH as the only predictor. Models were evaluated using a series of goodness-of-fit measures, including fit index (R^2), root mean square error (RMSE), bias, and corrected Akaike information criterion (AICc). All of the models fit the data very well, with 96 to 98% of the variation explained for loblolly pine, and 96 to 97% explained for shortleaf pine. Similarly, few differences were apparent in RMSE, bias, and AICc, although it was clear that the Curtis-Arney function fit both pine species slightly less well across the upper range of the diameters. Only subtle differences appeared in curve shape for small- to moderate-sized pines, with increasing departures predicted above 75 cm DBH. Given their overall similarity in performance, the modified logistic function was the preferred height-diameter model because of its more intuitive allometry at the upper extreme of pine size, especially when compared to the original FVS height dubbing equation. A unified height-diameter model capable of predicting total tree height for either pine taxa was also developed with a modified logistic function.

Introduction

Tree height is one of the most important measures used to describe forests, as it directly relates to the competitive interactions between plants, fiber yield, stand structural complexity, and habitat suitability for many organisms. As valuable as this information is, this metric is often neglected because the determination of total tree height is a time-consuming process prone to error if improperly done. As an example, those conducting large-scale forest inventories often choose to predict tree height as a function of a much easier to assess attribute (bole diameter) rather than measuring it directly (Bechtold et al. 1998, Barrett 2006). Modeling height may not optimally fit any given tree, but over the course of a large inventory, it often proves an economic balance of measurement efficiency and accuracy (Barrett 2006).

Unfortunately, our need to reliably measure tree height often exceeds our capacity to accurately forecast this variable. It is not because we lack the tools to do so—there are many models to predict tree height from diameter. Rather, choosing the appropriate model using the best measurement technique has not been done for most species in most locations. This is true even for commercially important taxa at major research locations. For instance, we have no local height equations for loblolly (*Pinus taeda*) or shortleaf (*Pinus echinata*) pine on the Crossett Experimental Forest in Ashley County, Arkansas, even though scientists have studied these taxa there since the mid 1930s.

Local height equations are particularly valuable in that they are derived using specimens found in the immediate study area. Thus, these equations better reflect nuances in tree allometry attributable to local conditions. Theoretically, such a model is preferable to ones developed for individual states, or even the entire southeastern United States (e.g., Bechtold et al. 1998, FVS Staff 2008). Hence, this study was initiated with the objective of developing the most accurate height-diameter model possible given a sample of loblolly and shortleaf pines taken from the Crossett Experimental Forest and surrounding areas.

Materials and Methods

Study areas

The Crossett Experimental Forest (CEF) covers 680 ha in the extreme southern portion of Ashley County, 11 km south of the city of Crossett. The CEF landscape is dominated by upland forests of loblolly and shortleaf pine, with a minor and varying hardwood component. Most of the soils on the CEF are silt loams, and are considered to be of good quality for growing pine, with loblolly site index of 25 to 30 m (50 year base age) (Gill et al. 1979). Virtually all of the pines on the CEF are of natural origin (i.e., naturally regenerated from local seed sources). Pine

seedlings, saplings, and small poles are abundant across the experimental forest. However, most of the pine overstory on the CEF is mature (> 40 years old), with extensive areas of even-aged and uneven-aged stands (Baker and Bishop 1986). In certain locations, sawtimber-sized individuals exceeding 75 cm in diameter can be found, although silvicultural practices usually mean this is an upper size limit.

Because of the maximum pine size threshold imposed by decades of intensive management over most of the CEF, a small number of exceptionally large loblolly (25 trees) and shortleaf (19 trees) pine were sampled on the nearby Levi Wilcoxon Demonstration Forest (LWDF). The LWDF is an unmanaged old-growth pine-dominated stand owned by Plum Creek Timber Company located roughly 16 km to the northeast of the CEF in Ashley County (Bragg 2004). The LWDF occurs on comparable landforms, has a similar range of site qualities as seen on the upland forests of the CEF, and (because of its age) has substantially larger specimens of both loblolly and shortleaf pine than the CEF.

Sample tree selection and measurement

Most of the CEF sample of pines across the full range of diameters at breast height (DBH, or the stem diameter at 1.37 m above the ground surface) were collected by systematically locating four 0.13-ha circular plots in randomly selected compartments. A number of additional small diameter pines were sampled along the roads on the CEF to ensure these size classes were not underrepresented. As stated earlier, a few dozen trees were measured on the LWDF to supplement the CEF loblolly and shortleaf samples.

Pines less than 3 cm DBH had their DBH measured to the nearest millimeter using a hand caliper, and larger pines had their DBH measured (to the mm) with a steel diameter tape. For the 415 loblolly pines examined, DBH ranged from 0.3 cm to 108.2 cm, and of the 143 shortleaf pines sampled, DBH varied from 0.3 cm to 91.9 cm (Figure 1). Without the LWDF additions, the maximum CEF loblolly and shortleaf pine diameters would have been 78.0 cm and 80.8 cm, respectively.

Total tree height was measured using one of two approaches. For pines up to about 10 m tall, a telescoping pole was used to estimate height to the nearest 3 cm. Taller trees were measured using a TruPulse™ 200 laser hypsometer following the sine method of height determination. The sine method is more accurate and precise than the tangent-based approach incorporated in the factory-default TruPulse height routine because it directly measures the crown of a tree, rather than approximating it with angles and a baseline distance (Blozan 2006, Bragg 2008).

With the sine method and the TruPulse hypsometer, pine height can be reliably estimated to the nearest 15 cm for very large trees (the accuracy of the tangent method with this hypsometer is probably between ± 1 to 3 m, and can exceed 5 m for some trees).

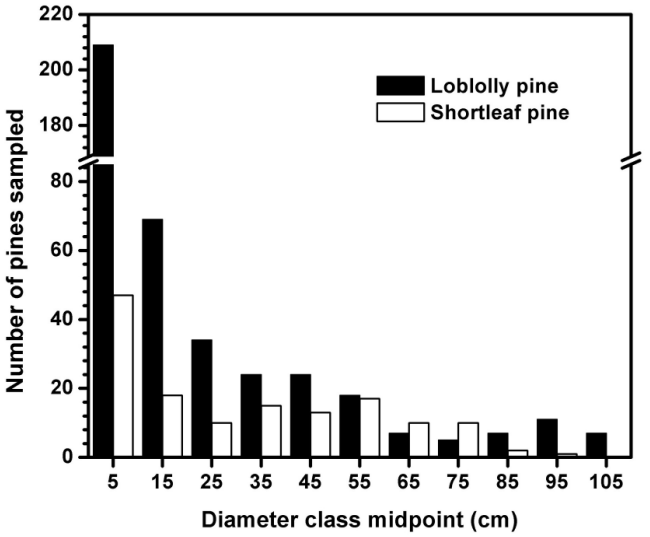

Figure 1. Diameter class distribution of loblolly and shortleaf pines selected for height-diameter model fitting.

Height model selection and statistical comparisons

Many height-diameter models exist—for instance, Huang et al. (2000) evaluated 27 different functions for stands of white spruce (*Picea glauca*) in the boreal forests of Canada. Rather than testing the scores possible, a dozen commonly used height-diameter models were fit using weighted nonlinear least squares regression with DBH as the only independent variable (and the inverse of DBH as the weight of the loss function). These were compared graphically for their fit to the data, and the four best performers (the Chapman-Richards, modified logistic, exponential, and Curtis-Arney functions) were retained for further comparison.

The Chapman-Richards function is as follows:

$$HT = 1.37 + b_1\left(1 - e^{-b_2 DBH}\right)^{b_3} \quad (1)$$

where predicted pine height (*HT*, in m) is a function of *DBH* and a set of species-specific coefficients (b_1, b_2, b_3, …, b_n). The modified logistic equation:

$$HT = 1.37 + \frac{b_1}{1 + (1/b_2)DBH^{b_3}} \quad (2)$$

and the Curtis-Arney (also known as the Korf/ Lundqvist) function:

$$HT = 1.37 + b_1\left(e^{b_2\left(DBH^{b_3}\right)}\right) \quad (3)$$

also used the same predictor and same number of

coefficients. Finally, the exponential function:

$$HT = 1.37 + b_1\left(e^{b_2 + b_3\left(b_4/(DBH + b_5)\right)}\right) \quad (4)$$

applied five coefficients but the same variable as the previous models.

As a final comparison, the height dubbing function of the Southern Variant of the Forest Vegetation Simulator (FVS) was used directly from its source (FVS Staff 2008). Unless provided by the user, the FVS height dubbing function is used to calculate height for every tree processed by the model. Hence, the coefficients given in the Southern Variant description (which covers Arkansas) are assumed applicable without modification to the pine sampled in this paper. Significant departures of the FVS height dubbing model from expectations are important, as this model is extensively applied across the region.

Models were evaluated using a series of goodness-of-fit measures, including fit index (R^2), root mean square error (RMSE), bias, and corrected Akaike information criterion (AICc). The fit index used in the statistical analysis package (Statistica, version 8.0) is a nonlinear analog to conventional R^2 used in linear regression (i.e., sum of squares residual (*SSR*) divided by the total sum of squares (*SST*)). RMSE equals:

$$RMSE = \sqrt{\sum_{i=1}^{n}\left(HT_i - \hat{HT}_i\right)^2 / (n-p)} \quad (5)$$

where HT_i is the height of the i^{th} pine, $\hat{HT}_i$ is the predicted height of that pine, n is the total number of observations, and p is the number of function parameters. Bias was determined by:

$$Bias = \sum_{i=1}^{n}\left(\hat{HT}_i - HT_i\right)/n \quad (6)$$

where bias is negative if the predicted height is less than the actual (measured) height. AICc is a measure that allows for the comparison of multiple models with differing numbers of parameters:

$$AICc = 2p + n\left(\ln\left(\hat{\sigma}^2\right)\right) + \frac{2p(p+1)}{n-p-1} \quad (7)$$

and $\hat{\sigma}^2 = \sum \hat{\varepsilon}_i^2 / n$. This version of the AIC is preferable because it has a second order correction for limited sample sizes (Burnham and Anderson 2002). Smaller AICc values indicate better models.

Results and Discussion

Evaluating model fit

The functional forms in this paper did a good job of matching the overall trends in tree size. All of the models explained between 96 and 98% of the variation in both pine species (Table 1). Similarly, few differences were apparent in RMSE, bias, and AICc. For all but the Curtis-Arney equation, RMSE averaged around 1.85 m for loblolly pine and 2.43 m for shortleaf, suggesting that departures between predicted and actual heights were limited (even the Curtis-Arney differed by only 2 m). These models showed little evidence of bias in their fit, regardless of species.

While there were subtle differences in the AICc values for all functional forms within each species, only the Curtis-Arney departed noticeably from the others. The Chapman-Richards, modified logistic, and exponential functions were within 4% of the others' AICc scores for both pine species, and 4.8 to 20.4%, respectively, with the Curtis-Arney equation.

Figures 2 and 3 show how each model form fit the actual loblolly and shortleaf pine data, respectively. Importantly, each of the functions tracked the relationship between height and diameter in both pine species well, including the rapid increase in height with diameter at small DBH, followed by a slowing trend as the trees reached moderate (30 to 40 cm DBH) size.

Table 1. Sample size and goodness-of-fit measures by height-diameter model for pines from the CEF and LWDF.

Height-diameter model	n	R^2	RMSE	Bias	AICc	ΔAICc	%AICc
			Loblolly pine				
Chapman-Richards	415	97.56	1.83	0.004	505.73	0.00	100.0
Modified logistic	415	97.49	1.86	0.010	515.91	10.18	102.0
Exponential	415	97.44	1.88	-0.065	525.01	19.28	103.8
Curtis-Arney	415	96.86	2.07	0.018	608.87	103.14	120.4
			Shortleaf pine				
Chapman-Richards	143	96.53	2.43	0.006	256.76	1.95	100.8
Modified logistic	143	96.47	2.45	0.010	259.20	4.39	101.7
Exponential	143	96.58	2.41	-0.022	254.81	0.00	100.0
Curtis-Arney	143	96.27	2.52	-0.080	267.01	12.20	104.8

ΔAICc = model AICc – minimum AICc; %AICc = (model AICc/minimum AICc) x 100

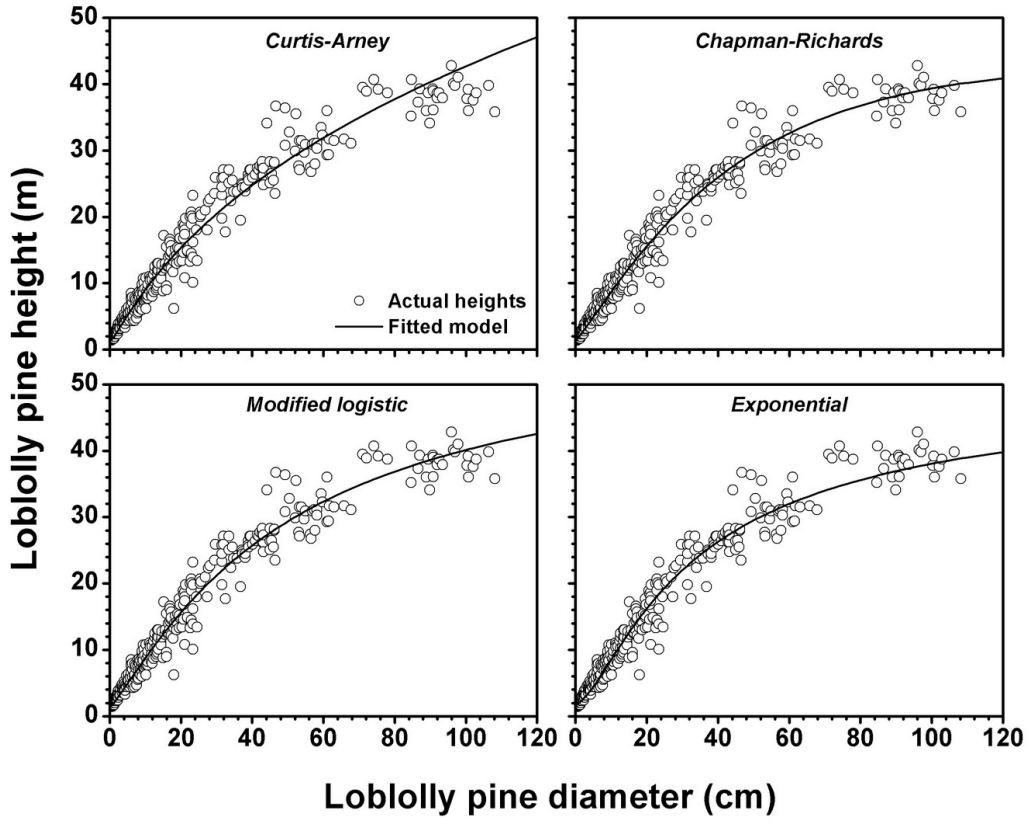

Figure 2. Fit of different models to the loblolly pine data used to derive the equations.

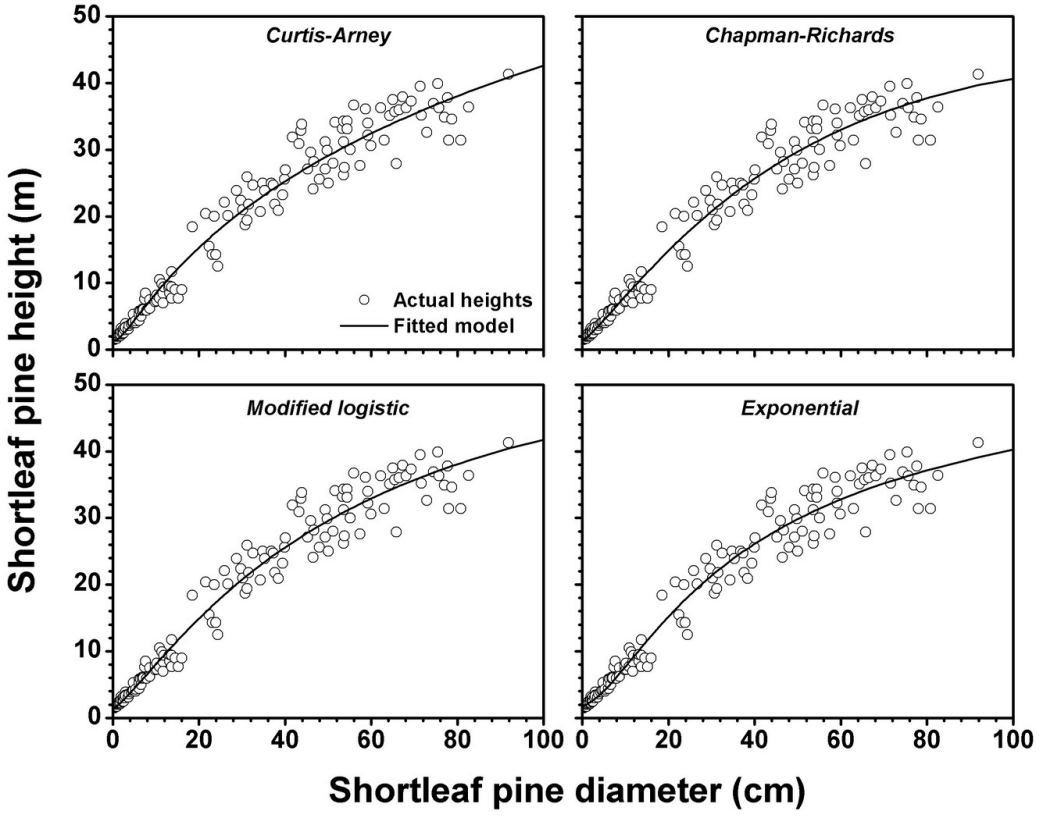

Figure 3. Fit of different models to the shortleaf pine data used to derive the equations.

Model comparisons

Further comparisons can be made by including the default equation from the Forest Vegetation Simulator (FVS—see Table 2 for coefficients of both species for all equation forms). The FVS height equations, which use the Curtis-Arney form, are provided for evaluation only—it would be inappropriate to compare their fit to those models developed in this paper because of differences in the data used.

It was clear that the Curtis-Arney function fit both pine species most poorly across the range of the diameters (Table 1). Figures 2 and 3 indicate that the most prominent departures created by using the Curtis-Arney function occur in the largest size classes. The Curtis-Arney notably over-predicts the height of large diameter pines, a trend especially noticeable with loblolly pine (Figure 2). This tendency is even more apparent when extended towards the upper size limits of both species (Figures 4 and 5). For instance, the Curtis-Arney equation predicts an almost 60 m tall loblolly pine at 200 cm DBH, an improbable height for this species in Arkansas.

The champion-sized loblolly pines in Figure 4 are intended to provide context for predictions beyond the original data range. Note that the only one of these trees measured with the same sine-based method used in this paper is the current national champion, located in the Congaree Swamp National Park in South Carolina. The other, more local champions were probably measured with either the tangent or similar triangle methods, both of which can be much less reliable (Blozan 2006, Bragg 2008). Unfortunately, at least three of these champion trees are now dead and cannot be remeasured with the sine method to verify their heights. If we assume that the heights reported for these trees are reasonable, it can be inferred from Figure 4 that most of the equations would do a reasonable job of predicting very large loblolly pines.

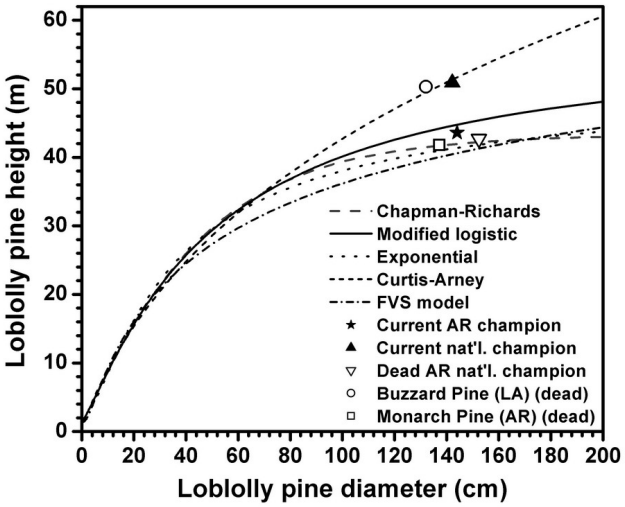

Figure 4. The height predictions of the loblolly pine models derived for this paper, the FVS dubbing equation, and a handful of champion-sized pines. Loblolly pine height predictions are extended out to 200 cm DBH (a reasonable upper size possibility for this species, at least from historical records) to show the results of extrapolations beyond the range of the original data.

The Curtis-Arney function is probably too high in its height predictions, although it would do a better job of fitting the current national champion. However, the national champion loblolly pine is growing in a very favorable site (a fertile bottomland), which is not representative of conditions on the CEF.

It is apparent in Figures 4 and 5 that only subtle differences in curve shape, and hence, height prediction, are realized in small- to moderate-sized pines, regardless of the model used. Even the FVS height dubbing equation does remarkably well up to about 40 cm DBH for both loblolly and shortleaf pine.

Table 2. Model coefficients by pine species from individuals measured on the CEF and LWDF.

Species	Coefficient	Chapman-Richards	Modified logistic	Exponential	Curtis-Arney	FVS dubbing [a]
Loblolly pine						
	b_1	41.9641	55.9834	2.2595	499.0730	243.8606
	b_2	0.0247	0.0103	3.0866	-7.0057	4.2846
	b_3	1.1496	-1.1703	-10.6490	-0.2246	-0.4713
	b_4	--	--	3.0016	--	--
	b_5	--	--	6.5158	--	--
Shortleaf pine						
	b_1	44.3850	59.8416	5.0109	195.5000	444.0922
	b_2	0.0235	0.0076	2.4111	-7.0638	4.1188
	b_3	1.2117	-1.2175	-10.7870	-0.3287	-0.3062
	b_4	--	--	3.6285	--	--
	b_5	--	--	7.9802	--	--

[a] Coefficients given for loblolly and shortleaf pine height equations (Curtis-Arney functions) taken from FVS Staff (2008).

However, total tree heights for larger shortleaf pine on the CEF would be significantly under-predicted using the current FVS height model, as would the biggest of the loblolly pines.

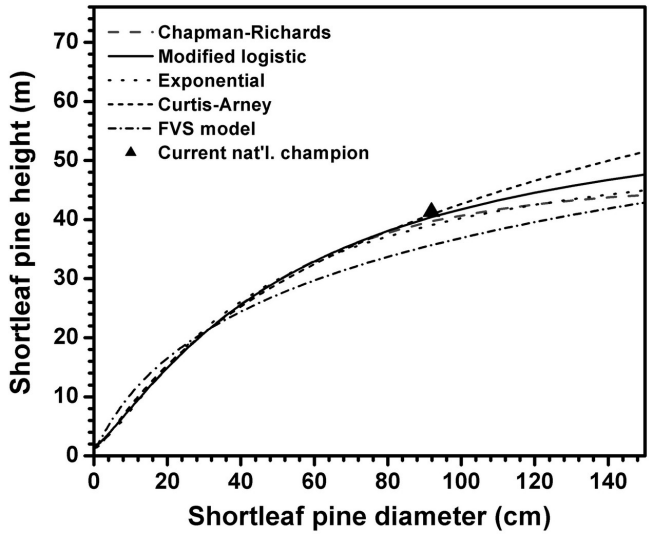

Figure 5. The height predictions of the shortleaf pine models derived for this paper, the FVS dubbing equation, and a single champion-sized pine (the current national champion shortleaf pine, found on the LWDF). Shortleaf pine height predictions are extended out to 150 cm DBH (a reasonable upper size possibility for this species, at least from historical records) to show the results of extrapolations beyond the range of the original data.

Model recommendation for the CEF

Given their overall similarity in performance, the modified logistic function was the preferred height-diameter model because of its more intuitive allometry at the upper extreme of pine size. This recommendation is made in part of how much the other equations (with the exception of the Curtis-Arney, which has already been rejected because of its behavior with large diameter pines) flatten in their height projections over 100 cm DBH. Even though the modified logistic equation's ΔAICc value (Table 1) is generally interpreted as providing only limited support for the equivalence of this model and the exponential and Chapman-Richards equations, the differences were not drastic. More importantly, the modified logistic function allows for some height increment in these big trees without being too aggressive. Thus, it is capable of capturing the likely allometric patterns of very large trees without significant departures from the more conservative height-diameter models at small to moderate diameters (Figures 6 and 7).

A comparison of the modified logistic and FVS models show that there are definite advantages in using a local height equation. For loblolly pine, the difference between the two differed little until moderate-sized diameters are reached, after which the FVS equation noticeably under-predicts loblolly height. Shortleaf pine behaved somewhat differently, with the FVS model slightly over-predicting heights for some small diameter pines (Figure 7) and under-predicting heights for moderate to large shortleaf.

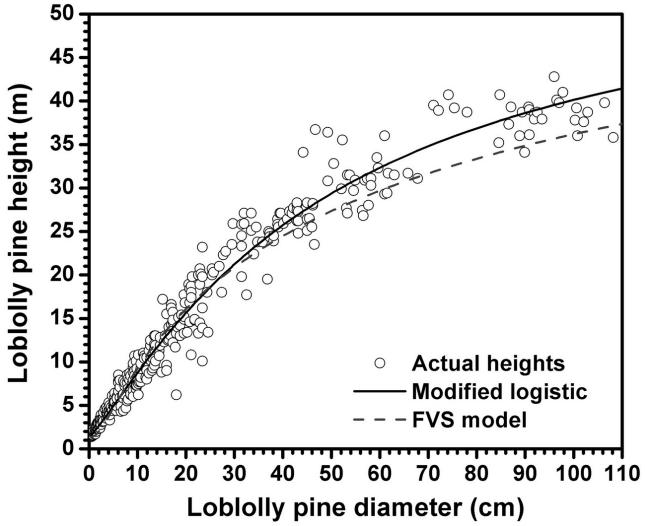

Figure 6. Comparison of recommended modified logistic and FVS height-diameter models on loblolly pine from the CEF and LWDF.

There would likely be little impact of the slight overestimate for small shortleaf, but at the largest size classes of both pine species, the FVS model would under-predict heights by about 5 m. Given that the CEF is primarily managed for sawtimber, such a departure could have significant ramifications when the current FVS model is applied.

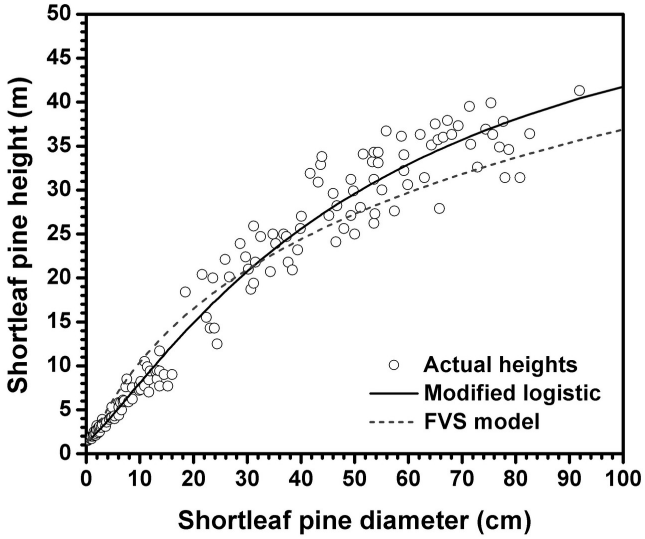

Figure 7. Comparison of recommended modified logistic and FVS height-diameter models on shortleaf pine from the CEF and LWDF.

A unified pine model

A cursory examination of the data for both loblolly and shortleaf pine suggested that there were few differences in the height-diameter allometry between these species for the CEF—so few, in fact, it is possible to derive a "unified" height-diameter model to project either species. The following modified logistic equation was fit to all 558 pines:

$$HT = 1.37 + \frac{57.4042}{1 + 103.9933 DBH^{-1.1760}} \quad (8)$$

and explained over 97% of the variation (Figure 8).

A unified model, though slightly biased and not as precise as one developed for each species (Table 3), does have a number of key advantages. For instance, distinguishing between small stature loblolly and shortleaf pine can often prove difficult in the CEF area, especially when the young twigs cannot be examined. A generic pine model makes it less critical that species are known exactly in order to predict their height.

It is also appropriate to use equation (8) to assist in stand structure reconstructions from historical inventories that may not be adequately differentiated—General Land Office surveyors in Arkansas, for example, did not separate pines into loblolly or shortleaf, but rather called any member of the genus *Pinus* "pine." In this example, the uncertainty in taxonomic classification cannot be corrected. The use of this generic model should provide more appropriate estimates of pine height, regardless of species.

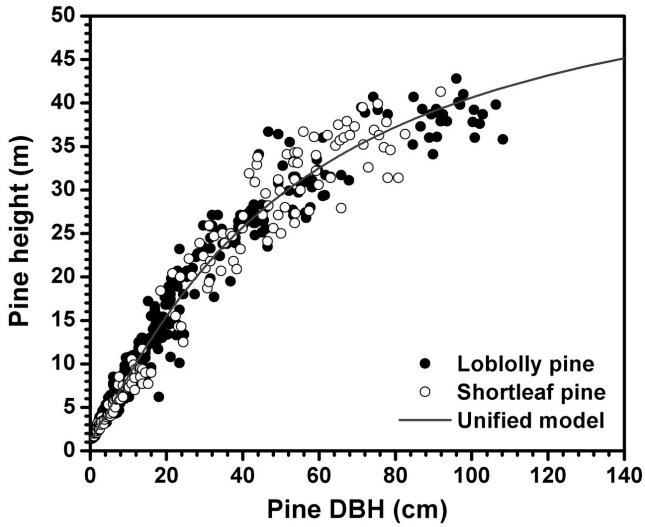

Figure 8. Height-diameter equation fit to all pine data sampled in the CEF and LWDF.

Table 3. Comparison of model height predictions using the modified logistic regression models developed specifically for loblolly, shortleaf, and both pines combined.

	Predicted height (m)					
DBH (cm)	Loblolly model	Unified model	Difference	Shortleaf model	Unified model	Difference
5	4.91	4.81	-0.10	4.44	4.81	0.37
25	18.58	18.45	-0.13	17.96	18.45	0.49
45	27.62	27.67	0.05	27.68	27.67	-0.01
65	33.61	33.85	0.24	34.35	33.85	-0.50
85	37.77	38.17	0.40	39.07	38.17	-0.89
105	40.79	41.33	0.54	42.52	41.33	-1.19
125	43.07	43.71	0.64	45.14	43.71	-1.42
145	44.84	45.57	0.73	47.17	45.57	-1.60

Conclusions

A local set of height-diameter equations is helpful when examining the patterns of tree allometry, especially for an area in which extensive scientific work is being conducted. This avoids the vagaries of models developed for other regions while allowing for the unique attributes of growth patterns in a specific location to be expressed. The data from this study confirm that a local height equation yielded a meaningful improvement in prediction accuracy when compared to the generic model incorporated in the FVS simulator.

This study also showed that if the bounds of the field data were not violated, there are many equations capable of expressing the relationship between pine height and diameter on the CEF.

The recommendation of the modified logistic function was made not because it was the absolute best fit of the data, but rather it fit the data comparably well and it seemed to do a more reasonable job of projecting pine height beyond the upper range of the diameters sampled. Such a trait is desirable, because even though it is statistically inappropriate to extend models beyond the range of data from which they were derived, users will almost inevitably do so—or may do so unwittingly, if the height equation is incorporated in a larger model system. Hence, it is logical to use a

model form that behaves reasonably for any conceivable diameter that may occur.

Acknowledgments

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Geographic Variation in the Pollination Biology of *Passiflora lutea* (Passifloraceae)

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Abstract

Like most species of *Passiflora*, *P. lutea* is reported to produce one-day flowers with complicated floral movements and requires deposition of non-self pollen for fruit production. Medium sized bees are the most likely pollinators in central Texas. We report on a series of observations and experimental manipulations that compare the reproductive biology of *P. lutea* in central Arkansas to that reported previously from plants about 800 km distant in central Texas. We observed floral movements and floral visitors, compared fruit production of flowers available to pollinators versus flowers from which pollinators were excluded, and compared fruit production of flowers that were hand-pollinated with self pollen versus flowers that were hand-pollinated with non-self pollen. Floral movements were similar to those of other *Passiflora*, with flowers opening for one day and styles that usually deflexed to a level below the anthers, presumably facilitating cross-pollination. Some flowers (20%) had styles that did not fully deflex. Movement of floral parts of plants in central Arkansas occurred slightly earlier than in plants in central Texas. Unlike what was observed in a small sample in Texas, we observed a low level of self-compatibility in *P. lutea*. In contrast to the medium sized bees that were the important pollinators in central Texas, *Anthemurgus passiflorae*, a small specialized andrenid bee that only forages on *P. lutea*, was likely the most important pollinator in central Arkansas. Finally, fruit set of plants in central Arkansas was much higher than that reported for plants in central Texas. Thus, this species varies geographically in its reproductive biology.

Introduction

Although all passionflowers (*Passiflora* spp.) produce complex flowers with structural similarities, species vary substantially in flower color and in the detail of flower structure and behavior. All species in this tropical and subtropical speciose genus have at least one ring of filaments (the corona) around a vertical stalk that supports the stamens and styles (the androgynophore) (Vanderplank 1991). Flower colors include red (e.g., *P. coccinea*), purple (e.g., *P. menispermifolia)*, greenish-yellow (e.g., *P. coriacea*), and white (e.g., *P. costaricensis*). The corona may consist of one (e.g., *P. citrina*), or two (e.g., *P. biflora*), or more (e.g., *P. caerulea*) series of filaments; the filaments may be long (e.g., *P. quadrangularis*) or short (e.g., *P. coriacea*).

In most species, the reproductive parts change their orientation after the flower opens. In these cases, the styles point upward when the flower opens but later bend (deflex) so the stigmas move downward. These movements bring the stigmas near visiting pollinators and appear to promote outcrossing (Janzen 1968). The details of these movements differ among species. For example, style movements are completed within 20 min of opening in *Passiflora foetida* (Janzen 1968) but are not completed in a second unidentified species until about 5 h after opening (Janzen 1968). *Passiflora vitifolia* is intermediate to these two species, with styles that begin deflexing 30-180 min after opening and taking up to 2 h to finish moving (Janzen 1968).

The diversity in floral morphology is accompanied by a diversity in pollen vectors. The red flowers of *Passiflora vitifolia* (Janzen 1968, Snow 1982), *P. speciosa* (Varassin et al. 2001), and *P. coccinea* (Storti 2002) are pollinated by hummingbirds. In contrast, *P. foetida*, an ill-odored species producing small flowers (6 cm) that are white, pink, purple, or blue, is pollinated by large bees (*Ptiloglossa* spp.) (Janzen 1968, Amela Garcia 1998). Large bees also pollinate *Passiflora amethystina*, *P. miersii* (Koschnitzke and Sazima 1977), and *P. caerulea* (Amela Garcia and Hoc 1997). Bats pollinate *P. penduliflora* (Kay 2001), *P. galbana* (Varassin et al. 2001), and *P. mucronata* (Sazima and Sazima 1998, Varassin et al. 2001). *Passiflora incarnata*, with purple, mauve, or white flowers, is pollinated primarily by *Xylocopa* bees (May and Spears 1988).

Most species of *Passiflora* appear to require animal pollination and to be self-incompatible. May and Spears (1988) excluded insect visitors from 52 flowers of *P. incarnata*; fruit production in these flowers was 0%, in contrast to a fruit production rate of 17% in flowers open to insect visitors. They also hand-pollinated flowers with self and non-self pollen. None of the flowers pollinated with self-pollen produced

fruit, but 80% of the flowers pollinated with non-self pollen produced fruit. Similarly, Snow (1982) saw no fruit set in 30 self-pollinated flowers of *P. vitifolia*, and Varassin et al. (2001) saw no fruit production in self-pollinated flowers of *P. alata* (*N* = 27), *P. galbana* (*N* = 25), *P. mucronata* (*N* = 56), and *P. speciosa* (*N* = 18). Animal pollinators are also required in *P. coccinea* (Storti 2002), *P. alata* (Koschnitzke and Sazima 1997), *P. amethystina,* and *P. moersii* (Koschnitzke 1997). In contrast, *P. suberosa* and *P. capsularis* (Koschnitzke and Sazima 1997) and *P. foetida* (Amela Garcia and Hoc 1998) are self-compatible. *Passiflora caerulea* exhibits a "low degree of self-compatibility" (Amela Garcia and Hoc 1997).

In addition to between-species variation, some species of *Passiflora* exhibit substantial within-species variation in floral morphology and behavior. For example, *P. incarnata* varies in color from lavender to mauve to white. Although most flowers of this species open in late morning, in some flowers the stigmas immediately begin to deflex while in other flowers the stigmas never deflex (May and Spears 1988). The cultivated *P. edulis* also varies in self-compatibility; the purple strain is self-compatible but the yellow strain is not (Vanderplank 1991).

Because it is a widely distributed species (from Pennsylvania to Kansas and south to Texas and Florida) (Vanderplank 1991), *Passiflora lutea* L. (Passifloraceae) provides a good test species for assessing geographic variation in floral behavior. This herbaceous vine produces small, greenish-yellow flowers. Its pollination biology has been studied in Austin, Texas (Neff and Rozen 1995). Like other *Passiflora*, *P. lutea* produces stigmas that usually deflex after the flowers open; however, Neff and Rozen (1995) noted the styles in some flowers never deflex, suggesting that these flowers never receive pollen and are therefore functionally male. Using indirect evidence, they concluded that medium-large bees (*Bombus*, *Xylocopa*, *Colletes*) pollinate *P. lutea.* Neff (2003) later concluded that *P. lutea* probably relies on a "mix of medium sized bees and wasps" for pollination. They experimentally showed that *P. lutea* requires an animal pollen vector and is self-incompatible. Our study provides a look at the pollination biology of *P. lutea* in another part of its geographic range (central Arkansas, approximately 800 km from the study site of Neff and Rozen). We examined the diurnal movement of flower organs, assessed which animal visitors were likely pollinators, and tested if *P. lutea* is normally cross-pollinated and if it is self-compatible.

Methods

Passiflora lutea grew at sites located both on the campus of the University of Arkansas at Little Rock and throughout the city. Because *P. lutea* spreads vegetatively, we considered each "clump" a single individual. We conducted observations of pollinators in June-August 1994 and 1997; we conducted experimental manipulations in June-August 1994-1996; we conducted additional observations of style movements in July 2005. All times are Central Daylight Savings Time.

We observed floral movements in 1994 and 2005. For three days in 1994, observations began 30 min before sunrise and ended 30 min after dark. During the course of the day, we watched the plant in 2-3 h shifts, with 30-60 min breaks between observation periods. During this time, we recorded the movement of floral parts through drawings. In 2005, we observed *Passiflora lutea* flowers to assess the percentage of flowers with non-descending (non-deflexing) styles. Between 1230 and 0130, we counted and categorized styles on seven plants as fully deflexed (stigmas below the anthers), partially deflexed (stigmas at the same level as the anthers), and non-deflexed (stigmas above the anthers).

For three weeks in 1994, we observed and counted flower visitors at 0700, 1000, 1200, 1600, and 1900. We noted the behavior of flower visitors and captured samples of each species for later identification. In 1997, we again observed the behavior of flower visitors, concentrating on the behavior of *Anthemurgus passiflorae*. Voucher specimens of *A. passiflorae* and *Megachile concinna* were deposited in the US National Pollinating Insect Collection with the USDA Bee Biology and Systematics Laboratory at Utah State University.

The first test of the breeding system was done to determine if *Passiflora lutea* normally requires a floral visitor for fruit production. First, we tagged flower buds that were about to open—50 buds on one vine in 1994, 50 buds on a second vine in 1995, and 20 buds on each of three different vines in 1996. Half of the flowers on each plant were bagged with bridal veil to test whether the plant could spontaneously self-pollinate and set fruit. The remaining flowers were left unbagged, to be visited by pollinators. The individual flower buds in both groups were tagged and monitored for fruit production.

The next experiment tested if *P. lutea* was self-compatible. Flower buds were bagged several days before they opened. We bagged 50 buds on one vine in 1994, 50 buds on a second vine in 1995, and 20 buds on each of three different vines in 1996. As each

flower opened, we manually pollinated it, using a cotton swab. Half of the flowers were pollinated with their own (self) pollen and half were pollinated with a mixture (non-self) of pollen from two other vines. After hand pollination, all flowers were rebagged and monitored for fruit production.

We measured rates of fruit set in 1997 by counting the number of fruits on stems versus the number of flower scars on a total of 25 stems from plants at eight sites. For a given shoot, we made observations between the fruit closest to the meristem and, working away from the meristem, the first ripe (blue) fruit; this procedure allowed us to eliminate potential fruit sites that were too young to have enlarged fruit and sites that had lost ripened fruits through dispersal.

Results

Passiflora lutea flowers remained open for only one day. Before opening, the styles were vertical and pointed upward and the filaments and anthers were vertical and pointed downward. The petals began to open around 0700 and most were fully open by 0800. As the petals opened, the 5 free filaments moved upward until they were horizontal and the 5 anthers hung vertically from the filaments. In late morning, there was a drastic change in style and anther position. Most styles, originally vertical and pointing upward, descended (deflexed) until they were below the filaments. At the same time, the anthers curled upward until they paralleled the base of the flower. Most flowers completed this shift by 1200 and remained in this position for most of the afternoon. At approximately 1600, the petals began to close, the filaments and anthers began to abscise and the styles began to move upward. This process continued until the styles were again vertical and pointed upward, the filaments and anthers were vertical and pointed downward and the flower was closed. By sunset, all flowers were closed. These organ movements were not induced by pollination. The same movements were observed in both the unbagged flowers that were visited by insects and in the bagged flowers that were not visited.

Although most flowers (80%) behaved in the manner describe above, styles of some flowers did not deflex completely. By 1230, 14.3% of the styles had deflexed until the stigmas were at the same level as the anthers and 5.7% of the styles remained vertical with the stigmas pointing upward.

Insect activity began as early as 0700 and few insects visited after 1700 (Fig. 1). Most visits occurred between 0800 and 1300. The peak in activity was approximately 1000.

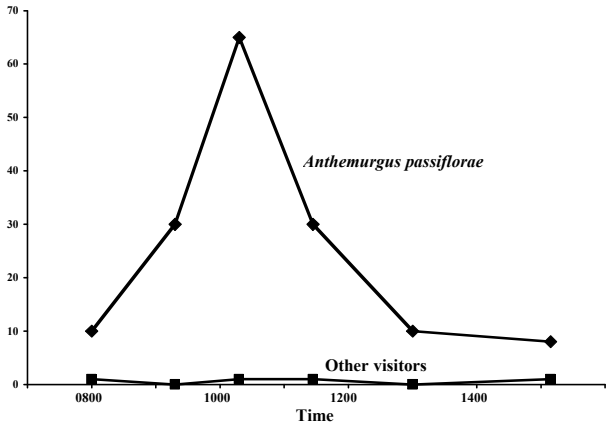

Figure 1. Total number of visitors observed at *Passiflora lutea* during 6 observation days. Each point represents visitors within 15 min before to 15 min after the time on the X-axis. Upper line is number of *Anthemurgus passiflorae;* lower line represents all other flower visitors combined.

Although there were several species of floral visitors, there was only one probable common pollinator, *Anthemurgus passiflorae*, an andrenid bee that has been observed only on *P. lutea* (Michener et al. 1994). A wasp, a bumblebee, a butterfly, and several species of flies and ants fed on nectar but probably did not pollinate the flowers because they did not contact the stigmas. A second bee, *Megachile concinna* (Megachilidae), was also a potential pollinator. Like other species of flower visitors, *A. passiflorae* and *M. concinna* collected nectar; unlike other species of flower visitors, these bees also collected pollen and, in doing so, contacted the stigmas. *Megachile concinna* was common at only one plant and this plant produced very few fruit (only two fruits of 60 possible). *Anthemurgus passiflorae* was most abundant between 1000 and 1200; by this time, floral movements had placed the stigmas and anthers close together and the bees contacted the stigmas as they collected pollen. *A. passiflorae* visited *P. lutea* in much greater numbers than did any of the other species. Thus, because of behavior and abundance, we concluded that *A. passiflorae* was the most important pollinator of *P. lutea*.

Fruits were abundant on open-pollinated plants in 1994-96. In 1997, when fruits were counted, fruit set ranged from 5% to 82% early in the season.

Passiflora lutea rarely set fruit without an insect vector. Only 3/25 (12%) bagged flowers in 1994, 2/25 (8%) bagged flowers in 1995, and 0/30 (0%) bagged flowers in 1996 produced fruit. In contrast, 20/25 (80%) unbagged flowers in 1994, 23/25 (92%) unbagged flowers in 1995, and 17/30 (56.7%) unbagged flowers in 1996 produced fruit. In 1994, 2

of the bagged flowers that produced fruit were found with dead bees in the bag. None of the other 3 bagged flowers that set fruit were likely to have been visited by insects. These results (chi square = 78.38, df = 1, $P < 0.001$) indicate that the plant almost always requires animals to visit and pollinate but that fruit production can occur in approximately 4% of the flowers without an insect vector.

Passiflora lutea was generally self-incompatible but there was a low level of self-compatibility. Only 2/25 (8%) flowers receiving self pollen in 1994, 6/25 (24%) flowers receiving self pollen in 1995, and 0/30 (0%) flowers receiving self pollen in 1996 produced fruit. In contrast, 18/25 (72%) flowers receiving non-self pollen in 1994, 21/25 (84%) flowers receiving non-self pollen in 1995, and 10/30 (33.3%) receiving non-self pollen in 1996 produced fruit. Considering the low number of fruit produced by the self-pollinated flowers (chi square = 45.81, df = 1, $P < 0.001$), it would appear that *P. lutea* usually requires another pollen source but that approximately 10% of the flowers can set fruit from self pollen.

Discussion

Although the floral biology of *Passiflora lutea* in central Arkansas was similar to that observed in central Texas, there were interesting differences.

Like other species of *Passiflora* (Vanderplank 1991), and like *P. lutea* in central Texas (Neff and Rozen 1995), *P. lutea* in central Arkansas produced one-day flowers that opened in the morning and closed before dark. Throughout the day, the movement of reproductive organs was consistent among flowers and similar to those of other *Passiflora* species (Vanderplank 1991). However, the timing of flower opening differed slightly. Because Austin is farther west in the time zone than Little Rock, we compared floral movements to time since sunrise (United States Naval Observatory 2006). Neff and Rozen (1995) write that in Austin, "flowers typically open between 0800 and 0900" or 1.5-2.5 h after sunrise while our data show that in Little Rock flowers open between 0700-0800, or 1-2 h after sunrise. Similarly, the timing of style movements differed slightly between the sites. In Austin, stigmas "typically do not descend to anther levels until after 1200"—5.5 h after sunrise—while in Little Rock, this movement was completed by 5 h after sunrise.

Fruit set of *Passiflora lutea* was much higher in Arkansas than in Texas. Fruits were abundant in Arkansas in 1994-1996. In 1997, when fruit set rate was quantified, nearly half the flowers set fruit ($\bar{x}$ = 48.5%, S. D. = 29.9). In contrast, Neff and Rozen (1995) saw no fruit set at all.

Another geographic difference in the pollination biology of *Passiflora lutea* was that the probable pollinators in the two areas differed. In central Arkansas, *Anthemurgus passiflorae* was the most important pollinator of *P. lutea*, based on both behavior and abundance. Working in central Texas, Neff and Rozen (1995) considered the pollination role of *A. passiflorae* "limited," partially because of the bees' "modest size." Writing in 2003, Neff concluded that the habits of *A. passiflorae* suggest it "may be a highly effective pollinator of *P. lutea*" but doubted that it contributes significantly to pollination of *P. lutea* because it is "probably a rare bee"; he continued to argue that *P. lutea* probably depends on medium sized bees and wasps for pollination. Our observations showed, however, that because of the flower design and the anatomy *of A. passiflorae*, these bees were able to land on the flower and collect both nectar and pollen efficiently. The stigmas of the flowers we observed in Little Rock were well positioned to contact the bee and receive pollen as the bee crawled over the anthers. In Austin, however, female *A. passiflorae* "very rarely contact the stigmas while harvesting pollen" (Neff and Rozen 1995) and may be related to the earlier deflexing of styles in central Arkansas. The high fruit set of plants we observed further demonstrates the presence of successful pollinators in Arkansas.

The relatively large bees (e.g., *Bombus*, *Xylocopa*, *Augochloropsis* and *Colletes*) considered likely pollinators in central Texas by Neff and Rozen (1995) were not likely pollinators in central Arkansas. These bees were not probable pollinators in central Arkansas because: (1) flower visitors other than *Anthemurgus passiflorae* were rare and (2) most other flower visitors did not contact both anthers and stigmas. The only other flower visitor that contacted both anthers and stigmas was *Megachile concinna*. We observed this bee consistently on only one plant and this plant set very few fruit (3%), whereas plants visited by *A. passiflorae* had higher fruit set. We conclude that *Megachile concinna* only rarely pollinates *P. lutea* in central Arkansas. A photograph in Neff (2003) clearly shows that *Colletes latitarsis*, a medium-sized bee, can contact both stigmas and anthers and at least occasionally pollinate *P. lutea*.

Although most species of *Passiflora* appear to require an animal pollen vector and non-self pollen for fruit set (Snow 1982; May and Spears 1988; Koschnitzke and Sazima 1997; Amela Garcia and Hoc 1998; Varassin et al. 2001; Storti 2002), *P. lutea* in central Arkansas set a limited number of fruits without animal vectors and with self pollen. *P. caerulea*

(Amela Garcia and Hoc 1997), *P. foetida* (Amela Garcia and Hoc 1998), *P. suberosa* and *P. capsularis* (Koschnitzke and Sazima 1997) show limited self-compatibility. In contrast, Neff and Rozen (1995) observed no fruit set from 18 hand-pollinations with self pollen.

This study demonstrated that *P. lutea* varies in its pollination biology between two points approximately 800 km apart. There were slight differences in the timing of flower opening and style movements, much higher fruit set in Arkansas, and different probable pollinators. Perhaps other differences occur in the more eastern and northern parts of its range. In addition, this study demonstrated that *P. lutea* appears to be slightly self-compatible.

Acknowledgments

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Taking Another Look: Light n-Capture Element Abundances in Metal-Poor Halo Stars

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Abstract

Elements are produced in stars through a variety of processes; some are well known, others are still the object of active research. The elements Zirconium (Zr) and Yttrium (Y) are produced via neutron capture (n-capture). These elements reside in the mass range where there is uncertainty about the production mechanism at early time. The rapid n-capture process (r-process) was believed to be responsible for the production, but no study (Burris et al 2000, Gilroy et al 1988 and others) has been able to successfully use the r-process to reproduce the abundance signature for elements in this mass range for metal-poor halo stars. It has been suggested (Sneden and Cowan 2003) that there may be an undiscovered component to the r-process. New abundance calculations for these elements have been conducted for a sample of metal-poor halo stars. Transition probabilities for Zr II from (Malcheva *et al.*2006) and for YII from (Hannaford *et al.*1982) were utilized in these calculations as well as new high quality observational data from the Keck telescope. The new laboratory and observational data resulted in improvement in the abundance determinations and uncertainty of the abundances.

Introduction

All naturally occurring elements have astrophysical origins. The lightest of these, Hydrogen, Helium and a fraction of the Universe's Lithium were made within a few minutes after the Big Bang. Beryllium and Boron are created in the interstellar clouds of gas and dust during collisions between cosmic rays and gas nuclei. The other elements were created via various nuclear reactions in stellar interiors. Fusion reactions in stellar core produce elements up to Iron (A=56). However, fusion reactions beyond this point are endothermic; therefore stars cannot continue building heavier elements through fusion processes as there is no external source of additional energy. The process responsible for the creation of most isotopes beyond this Iron peak (Fe-peak) is the neutron-capture (n-capture) process.

There are two "main" processes that involved the capture of neutrons onto Fe-peak seed nuclei: the slow (s) and the rapid (r) n-capture processes originally identified in 1957 (Burbidge *et al.* 1957, Cameron 1957). The ultimate result of both type of processes is the same, a nucleus captures a neutron and increases its atomic mass. The difference between the two processes is the time scale over which they occur. In the s-process, the time between captures is on the order of thousands of years; while, in contrast, in the r-process many captures will occur in less than a second. The determining factors for process type are temperature and neutron density. All isotopes beyond the Fe-peak, regardless of origin, are much rarer than isotopes below the iron peak. This rarity in some cases carries over to their perceived value on Earth. Gold, Uranium and Platinum are all exclusively produced in the r-process.

The types of isotopes created in each process differ. In the s-process, nuclei never capture enough neutrons to move far from the valley of beta-stability, the region of atomic mass where isotopes of an element are stable to beta decay. When neutron capture yields an unstable nucleus, there is sufficient time for beta decay to occur, leading to a stable nucleus of atomic number one higher than the parent nucleus. This is not so in the case of the r-process, where captures occur in rapid succession, leading to isotopes of large atomic mass that are far from the region of beta-stability. However, as the available neutron flux density decreases, the r-process shuts down, allowing the beta decays to occur unimpeded. These nuclei arrive at the valley of beta-stability with atomic numbers much larger than the original nucleus. If the isotopic breakdown of elements above the iron peak is examined, it can be seen that each process contributes approximately equally to the observed elemental abundances. The conditions required to manufacture s-process isotopes can be reproduced in the laboratory and these have been well studied. However, those necessary for the r-process conditions are too extreme to allow them to be reproduced in the laboratory.

The environment required to produce each of these processes has long been of interest to astrophysicists. Because the s-process can be created in the laboratory, the conditions for it to operate can be unambiguously identified and located in nature (Sneden and Cowan 2003, Cowan and Thielemann 2004, Kappeler *et al*.

1989). The conditions needed are also generated in the shell-burning phase of Asymptotic Giant Branch (AGB) low to intermediate mass stars (Busso et al. 1999). These stars have lifetimes measured in billions of years. This is significant because n-capture elements created by stars via either process cannot be observed directly. To determine the abundances of elements produced within a star's interior it must evolve, die, and expel the material back into the interstellar medium (ISM). Then this material must be swept up during the formation of the next generation of stars where the elements can be detected as a part of the new star's atmosphere. Thus any s-process elements that are observed must have come from stars that lived on the order of billions of years prior to the formation of the star under observation. The s-process contribution to the abundances has been determined to have two components: main and weak. Each is responsible for the production of different mass ranges of isotopes and requires slightly different mechanisms within the AGB star. These phenomena have been studied and discussed by many authors (Kappeler *et al*. 1989, Gallino *et al.* 1998, Raiteri *et al.* 1993 and others).

Unfortunately, the situation is not so clear for the r-process. Several possible systems that could create the required conditions have been proposed (Burris *et al.* 2000, Sneden and Cowan 2003, Freiburghaus *et al.* 1999, Woosley *et al.* 1994). The most popular among these is the core collapse supernova (type II) originating from the death of stars that exceed 8 solar masses. These stars would live and die on timescales on the order of millions of years, matching the time scales required for r-process contributions (Woosley *et al.* 1994, Thompson 2003). Another proposed source is merging binary neutron stars, however, the frequency of such events is not believed to be high enough to account for the observed elemental abundances (Freiburghaus *et al.* 1999, Freiburghaus, *et al*. 1999, Meyer 1989). Of additional concern, none of the computer simulations of such mechanisms have been successful in reproducing the abundance signature observed in Solar System meteorites or in stellar spectra.

The complexities of the r-process are just beginning to be understood. The abundances of n-capture elements with $Z \geq 56$ agree well with r-process distribution obtained from the solar system material. Many examples support this result, including the results from some 50 metal-poor halo field giants (Burris et al 2000, Gilroy et al 1988, McWilliam et al 1995, Sneden et al 1996). As older halo objects, these stars formed prior to heavy enrichment from s-process sources. The r-process signature should dominate and good agreement is found for elements from Barium upward. However, a problem arises when the Solar System distribution is applied to the lighter n-capture elements as indicated in Burris *et al.* 2000. Strontium, Yttrium and Zirconium are the elements from this range for which observational data is available. No subsequent studies (Burris et al 2000, Travaglio et al, 2004, Cowan et al 2005) have been able to achieve reasonable agreement between the observed abundances of these elements and any combination of known s- and r-process components. It has recently been suggested by other authors that r-process is not a single component process as has been believed (Travaglio *et al*. 2004, Cowan *et al*. 2005, Sneden and Cowan 2003, Cowan and Thielemann 2004). These authors agree that the key to unlocking the mystery of this second r-process or light element process lies with further study of these lighter mass elements.

Methods

Our objective was to make new calculations for light n-capture elemental abundances in a group of metal-poor, and thus presumably old, Galactic halo stars. The trends in abundances of these elements over time have important implications for the understanding of the final stages of stellar evolution and of the chemical evolution history of the Milky Way Galaxy. A limited number of objects have lifetimes compatible with the time frame for the earliest contribution to the r-process elements. However failure of existing models to reproduce the element abundance signature over the entire range of atomic mass indicates that the site of the r-process is not known, and there may be two components to the r-process. These two processes operate in different environments and over different time scales. By choosing to examine specific elements, we were able to study the constraints on the type of objects and the parameters required for this potential second component.

The spectra utilized in this study are the same ones used by (Cowan *et al.* 2005). It is visible-region high-resolution spectra obtained from the Keck I HIRES instrument.

The spectra are taken over a wavelength range of 3150Å to 4600Å with a resolving power of R≈45,000. The signal to noise ratio of the spectra increased with wavelength for theses cool halo stars, ranging from 30 to 200.

The spectral synthesis program MOOG, developed by Chris Sneden (Sneden 1973) of the University of Texas, was used to obtain abundances of the elements in each star. The program generates 4 possible fits to the observed spectral line based on model atmosphere,

metallicity and spectral line atomic data supplied by the user. The model atmospheres for the stars were the same ones used by (Simmerer *et al.* 2004) which used a Kurucz model with no convective overshoot. A full discussion of the atmosphere parameters can be found in (Simmerer *et al.* 2004). The metallicity values for these stars were also adopted from the Simmerer survey. The atomic data was taken from the Kurucz line lists. The new oscillator strengths for Zr, as published in Malcheva *et al.* 2006, were used in lieu of the older data from Biemont *et al.* 1981. The Malcheva data supplies data for many wavelengths of astrophysical interest that had not been previously measured. The fit that most closely matches the observed spectra is then selected by the user to determine the abundance of the element. Because of the narrow wavelength parameters in the MOOG program and the spacing of the lines of interest (~10-20 Å), each line was synthesized individually and the abundances for each element were averaged from the results of individual lines. Figure 1a. is an example of a synthesis for Y 3600Å and 1b. is an example of Zr 3714Å for HD 204543.

Results

For the 6 program stars, a total of 4 singly-ionized Zr (Zr II) and 6 singly-ionized Y (Y II) lines were analyzed. The wavelengths of these lines are given in Table 1 along with the oscillator strength used to perform the synthesis. The average calculated abundance for each element (A) is presented in Table 2 along with the standard deviation for each element. The abundance results utilize the spectroscopic notation of log ε (A) where the number abundance (N_A) of the element is compared to the number abundance of Hydrogen (N_H). The spectroscopic notation for this format is

$$\log \varepsilon (A) = \log_{10}(N_A/N_H) + 12.0.$$

Also presented in Table 2 are the most recent results for these elements from other authors where available. The results from this analysis are in general agreement with previous work, with the lone exception of HD 135148. The reported results from Burris et al 2000 are likely erroneous, as inferior quality spectra were used and no statistical analysis was done on the abundance results. This discrepancy is not considered as a significant issue for this survey. We do find differences for the Zr abundance for HD 128279. Since both our survey and the Johnson et al. 2002 survey used similar quality observational data, we attribute this difference to the new values for log gf increasing the number of lines we were able to use in our abundance analysis. The variations seen in the abundance of Y for HD 74462 can be attributed to the superior quality observational data used in this survey. In both cases we were able to improve the uncertainty in the abundance values.

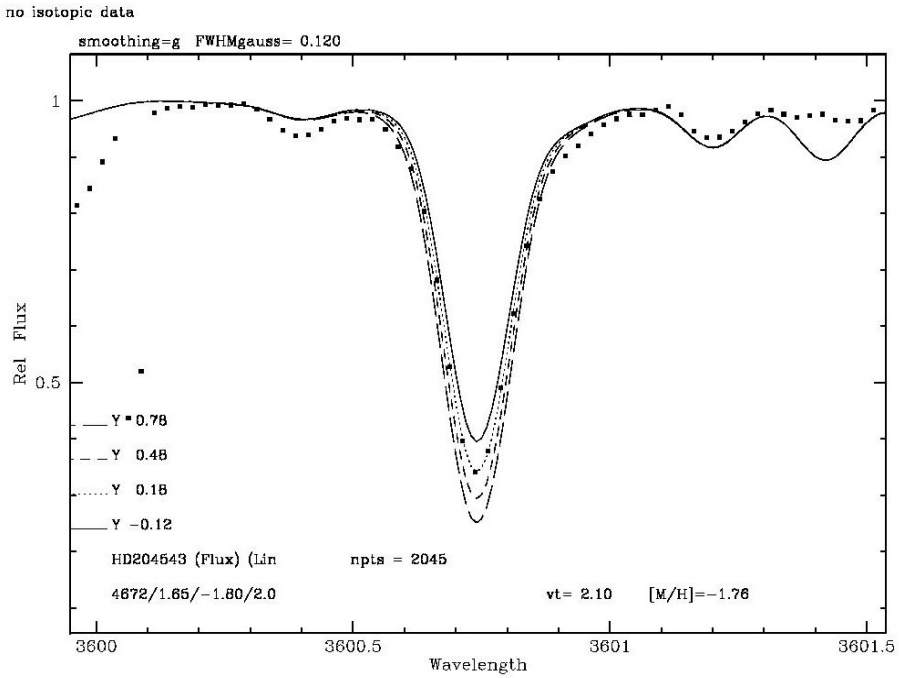

Figure 1a. An example of a spectral synthesis for the YII 3600Å line from HD 204543. The data was best fit for Y=0.18.

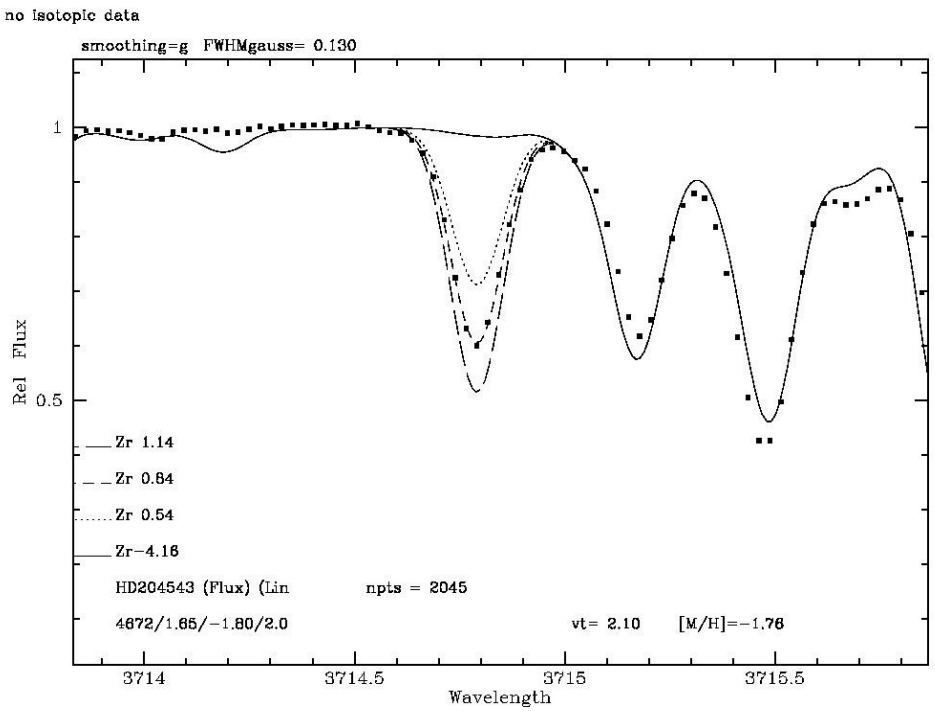

Figure 1b. An example of a spectral synthesis for the Zr II 3714Å line from HD 204543. The data was best fit for Zr=0.84.

Table 1. Program Wavelengths and Associated log gf values

Zr		Y	
λ (Å)	log gf (Malcheva *et al.* 2006)	λ (Å)	log gf (Hannaford *et al.* 1982)
3499	-0.81	3600	0.28
3505	-0.36	3611	0.01
3714	-0.93	3710	0.46
4050	-1.00	3747	-0.91
		3950	-0.49
		4398	-1.00

Table 2. New Abundance Values and Standard Deviation of Results compared to Previous Authors

Star	Zr	σ	Previous Results log ε/σ	Y	σ	Previous Results
BD +17 3248	0.62	0.14	0.76/ 0.14 (Cowan *et al*. 2002)	0.08	0.05	0.04/0.05 (Cowan *et a*l. 2002)
HD 74462	0.92	0.15	1.06/not done (Burris *et al* 2000)	0.03	0.07	0.54/not done (Burris *et al*. 2000)
HD 122563	-0.30	0.16	-0.28/0.25 (Montes *et al*. 2007)	-1.04	0.12	-0.93/0.20 (Montes *et al*. 2007)
HD 128279	0.21	0.02	-0.09/ 0.14 (Johnson *et al*. 2002)	-0.68	0.08	-0.72/ 0.15 (Johnson *et al*. 2002)
HD 135148	0.51	0.09	1.2/not done (Burris *et al*. 2000)	-0.18	0.08	1.22/not done (Burris *et al*. 2000)
HD 204543	0.85	0.11	0.97/not done (Burris *et al*. 2000)	0.12	0.08	0.28/not done (Burris *et al*. 2000)

To test for variations in the abundance, we recalculated the abundance value for Zr and Y while changing the temperatures in the model atmosphere. The range of temperatures varied from 4000K to 6000K, to encompass temperatures that are outside typical values for evolved giant stars. These temperature variations produced no apparent differences in the abundance synthesis. Other factors that will need to be explored are variations in metallicity, oscillator strength of the transitions and any effects from micro-turbulent velocity. The abundance dependence of these parameters will be explored in future work.

Discussion

To observe the abundance trends of the individual elements over the history of the galaxy, the [n-capture element/Fe] abundance ratios vs. iron metallicity [Fe/H] are plotted. The standard spectroscopic notation for comparison of element A to element B is given by

$$[A/B]=\log_{10}(N_A/N_B)_{star}-\log_{10}(N_A/N_B)_{Solar}.$$

In the heavier n-capture elements, the variation in the abundance values that exists at low metallicity disappears as metallicity increases. This scatter is interpreted as the effect of local nucleosynthesis events enriching the interstellar medium (ISM) nearby that has not had sufficient time to become homogenized. As time passes, there is a smooth distribution of the elements as the ISM becomes well mixed. The mixing time can be determined by looking at where scatter in the abundance ratio decreases. Also, the reduction in scatter can be an indicator of more common sources for production of the n-capture elements are contributing to the elemental abundances. The turn-on time of these events will eliminate certain objects, such as low mass stars, as potential early contributors to the r-process.

The abundances of Y and Zr are plotted versus s-process element Ba to observe any correlations. By comparison of these ratios, any inherent errors brought about by choices of atmospheric model parameters cancel out. During the early history of the Galaxy, Ba is produced via the r-process. Correlation between abundances of the two elements is indicative of a common source of production. If no correlation is seen, it will strengthen the likelihood of a "missing" light element process as suggested by some authors (Travaglio *et al.* 2004). Results indicate that the behavior of Y and Zr is not consistent with the abundance trends of Ba indicating that these elements might not be produced by the same process (Gilroy *et al.* 1988, Burris *et al.* 2000). The plot of [Y/Fe] vs. [Zr/Fe] compares abundances of Y and Zr for any correlation. If there is any commonality within this subgroup it indicates Y and Zr are produced in the same process. Figure 2 shows a strong correlation between the abundances of Y and Zr in these metal-poor stars.

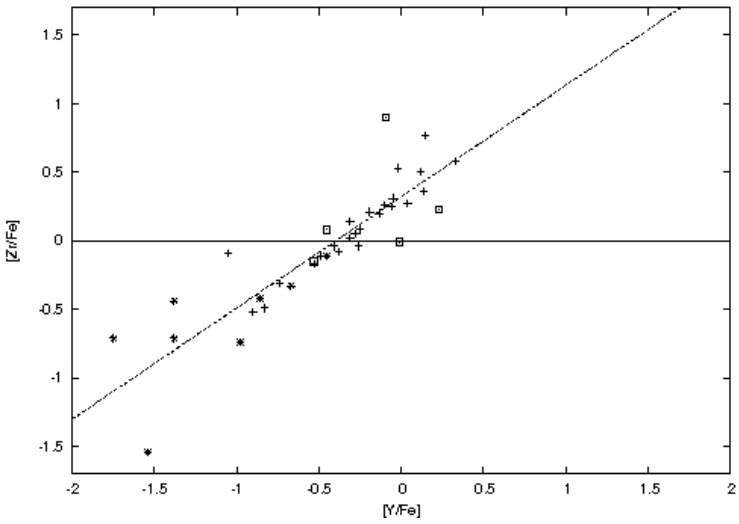

Figure 2. A comparison of the abundance of Zr to Y in a sample of metal-poor halo stars. Squares are from this work, plus signs from Francois *et al.* 2007, asterisk are upper limits from Francois *et al.* 2007.

A recent publication by (Francois *et al*. 2007) has given an unusual result for stars that are the most depleted in the n-capture elements. These stars appear to be depleted in Ba (as we expect), since Ba is primarily created in the s-process and thus is deficient early in the Galaxy's history when the r-process is responsible for its production. However, the same stars appear to be much more deficient in Sr providing further indications that Sr and Ba are not produced by the same process (Figure 3a). This provides further impetus to solve the riddle of this low mass regime, since clearly the same process is not responsible for the production of both Sr and Ba as was previously believed. We have included our results along with the data used in the Francois paper to determine if Y and Zr exhibit the anomalous behavior shown by Sr. The relationships of Y (Figure 3b) and Zr (Figure 3c) to Ba do not exhibit the same level of scatter in the observations described for Sr in the Francois paper. Therefore, we will next turn to the study of these depleted stars to search for elements not considered, such as Germanium, in the Francois paper to see if this unusual trend holds throughout the low mass n-capture range.

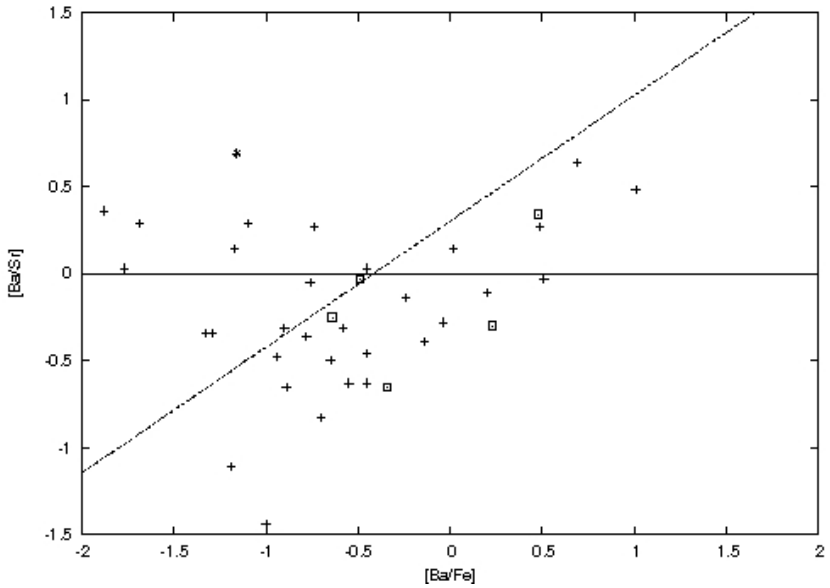

Figure 3a. A comparison of [Ba/Sr] to [Ba/Fe] after Francois *et al.* 2007. Symbols are those used in previous figure. Sr data for this work's stars are from literature.

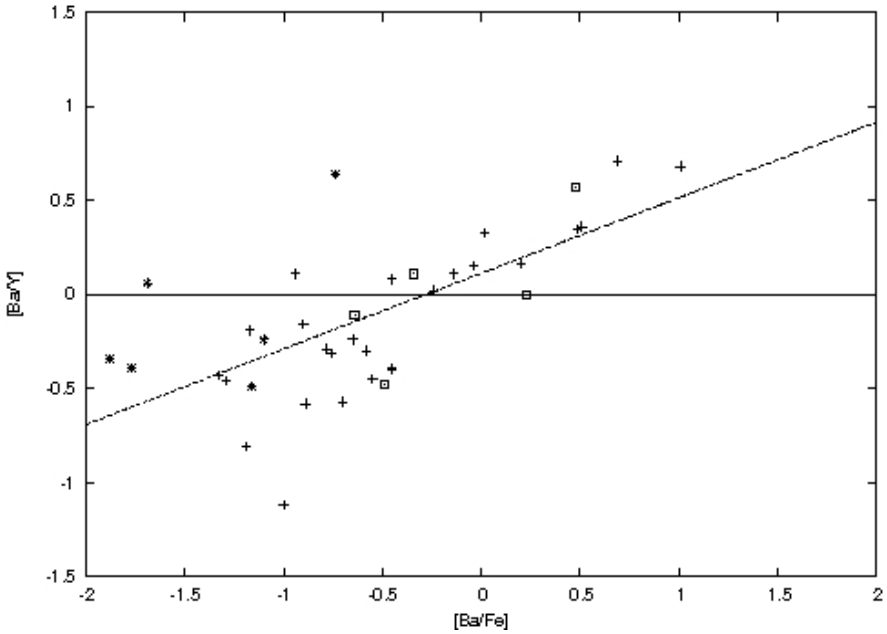

Figure 3b. A comparison of [Ba/Y] to [Ba/Fe]. Symbols are those used in Figure 2.

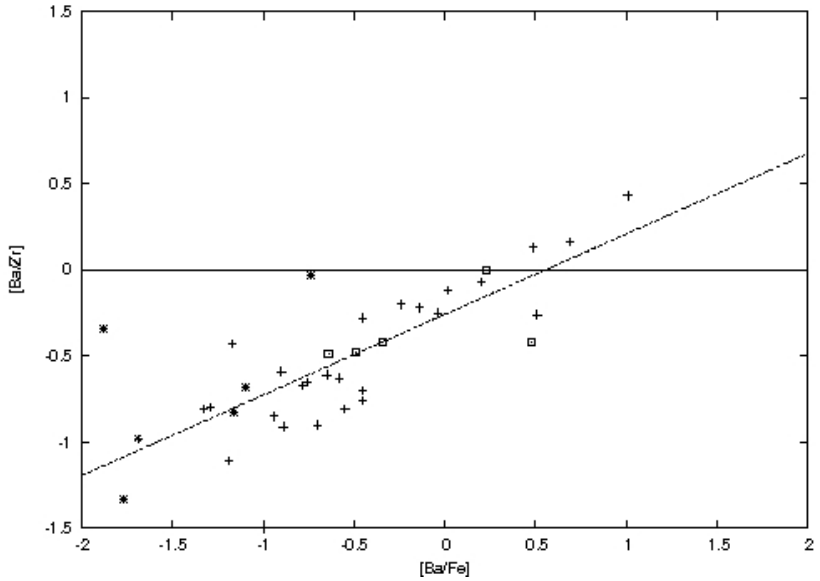

Figure 3c. A comparison of [Ba/Zr] to [Ba/Fe]. Symbols are those used in Figure 2.

Conclusions

We have performed new abundance calculations for the elements Y and Zr in 6 metal-poor halo giants using high quality spectra and in the case of Zr new atomic data. Our results are consistent with previous authors' analysis of these stars but with improved values for the uncertainty due to new laboratory data and better quality observational data.

Comparison of the abundances of lighter n-capture elements to those of the heavier s-process element Ba shows that there is no correlation between the production of the light elements to the heavy elements. This indicates that there seem to be two distinct processes operating early in the history of the Galaxy. The main r-process is responsible for production of the elements from Ba onward in atomic number while some as yet unknown process is responsible for the production of the lighter n-capture elements.

By comparing the abundance of the two light elements to one another, a distinct correlation can be seen. This indicates that these elements are produced in the same way, even if the mechanism is not known. The s-process, r-process or any combination of the two cannot reproduce the abundance signatures of these light elements. Therefore the production mechanism is a unique and undiscovered process that must have at least operated early in the history of the Galaxy.

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Amphibian, Reptile, and Small Mammal Associates of Ozark Pocket Gopher Habitat in Izard County, Arkansas

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Abstract

We conducted a study of the amphibian, reptile, and small mammal community assemblage of Ozark pocket gopher (*Geomys bursarius ozarkensis*) habitat in north-central Arkansas. We used 2 methods to capture individuals: hand capture and drift fences. During the study, we captured and marked a total of 9 anuran, 4 salamander, 5 lizard, 3 turtle, 16 snake, and 8 small mammal species exclusive of pocket gophers. We found one hatchling three-toed box turtle (*Terrapene carolina triunguis*) and one rough earth snake (*Virginia striatula*) inside a pocket gopher burrow and mound, respectively. Additionally, we witnessed both eastern racers (*Coluber constrictor*) and eastern coachwhips (*Masticophis flagellum*) retreat into pocket gopher burrows, as well as Hurter's spadefoots (*Scaphiopus holbrookii hurterii*) burrow into pocket gopher mounds when released. Our results highlight the importance of mammalian burrows, specifically pocket gophers, to other vertebrate associates in grassland ecosystems. Both conservationists and managers need to determine the pocket gopher's impact on ecosystem health and viability, specifically in natural grasslands, before conservation and/or management strategies are employed.

Introduction

Pocket gophers are fossorial rodents that mound dirt above ground while burrowing, which can alter the temporal microhabitat significantly. Prior to the 1990s, all pocket gophers in Arkansas were classified as Baird's pocket gopher (*Geomys breviceps*; Sealander and Heidt 1990). However, a second species, Ozark pocket gopher (*G. bursarius ozarkensis),* was described through further DNA testing and additional ectoparasite examination (Elrod et al. 1996, 2000). The Ozark pocket gopher is endemic to Izard County, Arkansas (Elrod et al. 2000, Kershen 2004), and is currently a "species of greatest conservation need" in the Arkansas Wildlife Action Plan (Anderson 2006). Thus, the Ozark pocket gophers' impact on the ecology of their habitat community should be determined before making future management/ conservation decisions. Previous studies have shown that pocket gopher habitats are high in species richness and provide abundant cover for associates (Howard and Childs 1959, Vaughan 1961, Wilks 1963).

As part of a larger study, we conducted an inventory of Ozark pocket gopher associates (i.e., amphibians, reptiles, and small mammals) found both on the surface and in the burrows. Our primary objective was to determine the amphibians, reptiles, and small mammals that use pocket gopher habitat.

Methods and Materials

Our study area consisted of 2 study sites (Site 1, Site 2) located on private property in Izard County, Arkansas. Both study sites were ~ 4 ha open, grassy cattle pastures bordered by small creeks, roads, and woodland.

We collected specimens along drift fences and by hand. Drift fences were placed at the periphery of the pastures, as we used drift fences to assess possible pocket gopher dispersal. We ran 2 drift fences per site at 2 sites for a total of 101 trap nights per site during 3 March to 2 July 2007 to capture species that co-exist with pocket gophers. The drift fences measured 33 m in length and had an 18.9 l bucket pitfall trap at each end with an additional 18.9 l bucket on either side of the drift fence every ca. 8 m (8 buckets per fence). We also placed a funnel trap 12 m from the end of the drift fence on either side. The funnel traps (90 x 30 x 30 cm) were made of 0.62-cm wire mesh hardware cloth and had double entrances.

We placed 2 additional drift fences at Site 2 from 2 January to 4 April 2008. These drift fences were similar to those described above, except, they lacked funnel traps. The funnel traps were not installed due to cold temperatures that would cause mortality to captured individuals.

We captured additional vertebrate species by hand at both sites by searching by sight and excavation of burrows during pocket gopher trap placement. Our hand capture collection technique was opportunistic where no specific transects or efforts were employed.

Typically, hand captures were limited to reptiles due to their ectothermy and basking behavior.

We identified all captured individuals to species or subspecies. We marked small mammals with ear tags using the same procedures as Fokidis et al. (2006) and the herpetofauna, exclusive of turtles, by either toe-clipping or scale-clipping (Nietfeld et al. 1996). We marked turtles by notching carapace scutes (Cagle 1939). We implanted passive integrated transponder (PIT) tags into snakes that were large enough to mark. We deposited voucher specimens of all amphibians and reptiles captured in drift fences and most of the hand captures in the Arkansas State University Museum of Zoology Herpetology Collection (ASUMZ; see Table 2). We deposited all small mammal specimens collected (i.e., trap mortality) in the Arkansas State University Museum of Zoology Mammalogy Collection (ASUMZ).

Results

Vertebrate Captures in Habitat

We captured 13 amphibian, 25 reptile, and 8 small mammal species or subspecies in Ozark pocket gopher habitat during field seasons in 2007 and 2008. Two subspecies of *Coluber constrictor* were captured, *C c. priapus* and *C. c. flaviventris*. Drift fences accounted for the majority of the species/subspecies collected in 2007 (Table 1). One additional species, tiger salamander (*Ambystoma tigrinum*), was captured in the drift fences in 2008 (n = 2 females; 6 February). Of the 18 families represented, 8 were amphibians (3 urodela; 5 anuran), 7 were reptiles (2 testudines; 5 squamates), and 3 were small mammals (2 insectivores; 1 rodent) (Table 2).

Table 1. Amphibian, reptile, and small mammals captured in drift fences in 2007 and 2008 at two Ozark pocket gopher habitat sites.

Scientific Name	Common Name	Site 1 (2007) No. Captured	Site 2 (2007) No. Captured	Site 2 (2008) No. Captured
Amphibians				
Acris crepitans blanchardi	Blanchard's Cricket Frog	1	4	0
Ambystoma opacum	Marbled Salamander	0	2	0
Ambystoma tigrinum tigrinum	Tiger Salamander	0	0	2
Bufo americanus charlesmithi	Dwarf American Toad	65	8	2
Bufo fowleri	Fowler's Toad	1	0	0
Eurycea lucifuga	Cave Salamander	1	0	0
Gastrophryne carolinensis	Eastern Narrowmouth Toad	3	4	0
Notophthalmus viridescens louisianensis	Central Newt	1	1	1
Pseudacris crucifer crucifer	Northern Spring Peeper	0	1	0
Rana catesbeiana	American Bullfrog	18	1	0
Rana palustris	Pickerel Frog	17	43	5
Rana spenocephala	Southern Leopard Frog	10	7	0
Scaphiopus holbrookii hurterii	Hurter's Spadefoot	18	11	1
Reptiles				
Cemophora coccinea copei	Northern Scarlet Snake	3	1	0
Aspidoscelis sexlineata viridis	Prairie Racerunner	30	5	0
Coluber constrictor priapus	Southern Black Racer	1	3	0
Coluber constrictor flaviventris	Eastern Yellowbelly Racer	0	1	0
Eumeces anthracinus pluvialis	Southern Coal Skink	2	3	1
Eumeces fasciatus	Five-lined Skink	3	3	0
Heterodon platirhinos	Eastern Hognose Snake	1	1	0
Lampropeltis calligaster calligaster	Prairie Kingsnake	1	0	0
Sceloporus undulatus hyacinthinus	Northern Fence Lizard	19	16	5

Table 1 continued

Scientific Name	Common Name	Site 1 No. Captured	Site 2 (2007) No. Captured	Site 2 (2008) No. Captured
Reptiles (continued)				
Scincella lateralis	Ground Skink	3	9	2
Tantilla gracilis	Flathead Snake	8	3	0
Terrapene carolina triunguis	Three-toed Box Turtle	3	1	0
Thamnophis sirtalis sirtalis	Eastern Garter Snake	0	1	0
Virginia striatula	Rough Earth Snake	1	0	0
Mammals				
Blarina carolinensis	Southern Short-tailed Shrew	0	4	0
Cryptotis parva	Least Shrew	10	89	8
Microtus pinetorum	Woodland Vole	21	41	9
Mus musculus	House Mouse	0	1	0
Ochrotomys nuttalli	Golden Mouse	0	2	0
Peromyscus maniculatus	Deer Mouse	19	14	0
Reithrodontomys fulvescens	Fulvous Harvest Mouse	14	14	0
Scalopus aquaticus	Eastern Mole	0	1	0

An additional 11 amphibian and reptile species were captured by hand. Box turtles and large snakes made up the majority of hand captures. We captured eastern racers (*Coluber constrictor*) and three-toed box turtles (*Terrapene carolina triunguis*) frequently (n = 14, 16, respectively). Eastern coachwhips (*Masticophis flagellum flagellum*) and prairie kingsnakes (*Lampropeltis calligaster calligaster*) were fairly common based on visual observations.

During this study, we documented 5 new county records. Four of those records were herpetofauna: eastern yellowbelly racer, *Coluber constrictor flaviventris* (Connior et al. 2007a); great plains rat snake, *Elaphe guttata emoryi* (Connior et al. 2007b); hurter's spadefoot, *Scaphiopus holbrookii hurterii* (Connior et al. 2007c); three-toed box turtle, *Terrapene carolina triunguis* (Connior et al. 2007d). Captures of Southern short-tailed shrew, *Blarina carolinensis*, also represented a new county record (see below).

Blarina carolinensis

Izard Co.--Found in a cattle pasture on private property off Co. Rd. 3, 4 km E of St. Hwy 9. UTM 15N 0597627E, 3987505N. 4 individuals. 20 March 2007 (1 individual; ASUMZ 28413); 25 April 2007 (1 individual; ASUMZ 28414); 26 April 2007 (2 individuals; ASUMZ 28415, ASUMZ 28416).

Vertebrate Observations in Burrows and Mounds

One of us (MBC) captured a juvenile three-toed box turtle inside a pocket gopher burrow while setting a live trap. Additionally, one of us (MBC) captured a rough earth snake (*Virginia striatula*) in a pocket gopher mound. Two of us (MBC, IG) witnessed both eastern racers and eastern coachwhips retreat into pocket gopher burrows and common map turtles (*Graptemys geographica*) digging nests in the soft dirt of pocket gopher mounds. After release of captured Hurter's spadefoots, they would commonly retreat by digging into pocket gopher mounds.

Discussion

Pocket gophers are ecosystem engineers, which not only provide habitat for other vertebrates but also impact the distribution of soil and nutrients (Reichman and Seabloom 2002, Reichman 2007). Other subterranean rodents, such as prairie dogs, have great impacts on the ecosystem and vertebrate fauna that elevate them to keystone species (Kotliar et al. 1999, 2006). Keystone species are species whose effect on the ecosystem is exceptionally larger than expected relative to its abundance (Power et al. 1996). Gopher tortoises (*Gopherus polyphemus*) have numerous vertebrate associates in their burrows as well (Lips 1991, Witz et al. 1991). Madison (1997) found that

Table 2. Complete list of all amphibian, reptile, and small mammal species captured in Ozark pocket gopher habitat in Izard County, Arkansas.

Scientific Name	Common Name	Scientific Name	Common Name
Class Amphibia	Amphibians	*Heterodon platyrhinos*	Eastern Hognose Snake
Ambystoma tigrinum tigrinum	Eastern Tiger Salamander[1]	*Lampropeltis calligaster calligaster*	Prairie Kingsnake
Ambystoma opacum	Marbled Salamander	*Lampropeltis getula holbrooki**	Speckled Kingsnake
Eurycea lucifuga	Cave Salamander	*Masticophis flagellum flagellum**	Eastern Coachwhip
Notopthalmus viridescens louisianensis	Central Newt	*Nerodia erythrogaster flavigaster**	Yellowbelly Water Snake
Bufo americanus charlesmithi	Dwarf American Toad	*Nerodia sipedon pleuralis**	Midland Water Snake
Bufo fowleri	Fowler's Toad	*Opheodrys aestivus**	Rough Green Snake
Acris crepitans blanchardi	Blanchard's Cricket Frog	*Storeria dekayi wrightorum**	Midland Brown Snake
Pseudacris crucifer crucifer	Northern Spring Peeper	*Tantilla gracilis*	Flathead Snake
Gastrophryne carolinensis	Eastern Narrowmouth Toad	*Thamnophis proximus proximus**	Western Ribbon Snake
Scaphiopus holbrookii hurterii	Hurter's Spadefoot[1]	*Thamnophis sirtalis sirtalis*	Eastern Garter Snake
Rana catesbeiana	American Bullfrog	*Virginia striatula*	Rough Earth Snake
Rana palustris	Pickerel Frog	*Agkistrodon contortrix contortrix**	Southern Copperhead
Rana sphenocephala	Southern Leopard Frog	**Class Mammalia**	Mammals
Class Reptilia	Reptiles	*Blarina carolinensis*	Southeastern Short-tailed Shrew
*Chelydra serpentina serpentina**	Common Snapping Turtle	*Cryptotis parva*	Least Shrew
*Graptemys geographica**	Common Map Turtle	*Scalopus aquaticus*	Eastern Mole
Terrapene carolina triunguis	Three-toed Box Turtle	*Microtus pinetorum*	Woodland Vole
Sceloporus undulatus hyacinthinus	Northern Fence Lizard	*Mus musculus*	House Mouse
Eumeces anthracinus pluvialis	Southern Coal Skink	*Ochrotomys nuttalli*	Golden Mouse
Eumeces fasciatus	Five-lined Skink	*Peromyscus maniculatus*	Deer Mouse
Scincella lateralis	Ground Skink	*Reithrodontomys fulvescens*	Fulvous Harvest Mouse
Cnemidophorus sexlineatus sexlineatus	Six-lined Racerunner	Key:	
Cemophora coccinea copei	Northern Scarlet Snake		
Coluber constrictor priapus	Southern Black Racer	*Hand Capture	
Coluber constrictor flaviventris	Eastern Yellowbelly Racer	[1] Species of Concern	
*Elaphe guttata emoryi**	Great Plains Rat Snake		

spotted salamanders (*Ambystoma maculatum*) almost exclusively used small mammal (*Blarina; Peromyscus; Microtus*) burrows for terrestrial refuge. Small mammal and gopher tortoise burrows provide refuge for numerous vertebrates throughout North America. Ozark pocket gophers provide similar refuge as the aforementioned species.

We documented 46 species or subspecies of herpetofauna and small mammals in pocket gopher habitat although only 5 species were actually captured or observed in gopher mounds or burrows. However, we suggest that the majority of species that were captured at both sites in drift fences probably utilized pocket gopher burrows in some way. Furthermore, certain species have been captured in pocket gopher burrows or habitat in multiple studies. Vaughan (1961) recorded 22 species of vertebrates using pocket gopher burrows in Colorado; Funderburg and Lee (1968) recorded 20 herpetofauna species inhabiting pocket gopher mounds in Florida. Both studies suggested that some of the species were true burrowers and relied on this habitat for survival.

We recorded substantially lower number of drift fence captures in 2008 vs. 2007 at Site 2. Drift fences were open from January through early April in 2008 of which the majority of the time was cold. Surface activity of both herpetofauna and small mammals was minimal. We probably would have recorded similar

results if the drift fences remained open into the summer, since surface activity was increasing at the end of this study.

Site 1 had an overflow reservoir adjacent to a creek that remained flooded for the majority of the year. This habitat feature explains the abundance of amphibians, especially juvenile dwarf American toads and American bullfrogs captured at this site compared to Site 2 (Table 1). Pickerel frogs (*Rana palustris*) were captured more frequently at Site 2; yet, both sites have clear, cool streams, which is preferred habitat (Trauth et al. 2004). Hurter's spadefoots (*Scaphiopus holbrookii hurterii*) were also captured frequently at both sites. Both *Scaphiopus* sp. and pocket gophers prefer sandy or friable soils and are expected to share the same geographic distribution (Wasserman 1958). Hurter's spadefoots are a "species of greatest conservation need" in Arkansas (Anderson 2006). The common occurrence of spadefoots in pocket gopher habitat may reflect their utilization of mounds and burrows of pocket gophers. In Texas, the only record of a *Scaphiopus holbrookii* (eastern spadefoot) in the Welder Wildlife Refuge was collected inside a pocket gopher burrow (Wilks 1963).

Tiger salamanders are also a "species of greatest conservation need" and are apparently absent from most of Arkansas except the northern one-third of the state (Trauth et al. 2004, Anderson 2006). They have been found in pocket gopher burrows in Arizona (Calef 1954), California (Howard and Childs 1959), and Colorado (Vaughan 1961). A similar species, California tiger salamander (*Ambystoma californiense*), have also been reported from pocket gopher burrows (Pittman 2005). Due to their fossorial behavior, areas with sandy or friable soils offer optimal habitat for this species (Petranka 1998). Thus, pocket gopher habitat may provide habitat that tiger salamanders can occupy easily due to the abundant loose, sandy soil. Vaughan (1961) stated that the occurrence of tiger salamanders in Colorado is determined by the presence of burrows. We suspect that the females we captured were moving to breeding sites since reproductively active females have been previously recorded during this time of the year (Trauth et al. 1990).

Although the three-toed box turtle is a new county record, they have been documented in surrounding counties (Trauth et al. 2004). Box turtles have been known to hibernate or seek refuge in mammal burrows (Vaughan 1961, Degenhardt et al. 1996, Nieuwolt 1996). Additionally, the mounds may supply box turtles along with other reptiles a place to bask.

Large snakes are commonly found in pocket gopher habitat probably due to the abundance of prey, including pocket gophers. The most common large snake we encountered was the black racer; several of which were observed both entering and exiting pocket gopher burrows. Although most racers probably do not prey on pocket gophers, larger individuals potentially could. Similar sized prey to the pocket gopher, such as weasels, rabbits, and large rodents, has been reported in the diet of racers (Fitch 1963). Another large snake species that was fairly common at the study sites was the eastern coachwhip. These snakes on occasion would retreat into pocket gopher burrows when alarmed. Johnson et al. (2007) documented eastern coachwhips using small mammal burrows as refugia; therefore, they may use pocket gopher burrows when available. Other large snakes have been recorded occupying pocket gopher burrows, such as *Pituophis* sp. (Vaughan 1961, Ealy et al. 2004, Himes et al. 2006, Rudolph et al. 2007). Eastern coachwhips are large enough that they could potentially prey on pocket gophers. Prairie kingsnakes occupy the same habitat as pocket gophers and their most common prey items are small mammals (Fitch 1999). Connior et al. (In Press) presented the first record of the prairie kingsnake preying on the Ozark pocket gopher. The ecological relationship between large snakes, such as coachwhips and kingsnakes, and Ozark pocket gophers is not known. However, pocket gophers may act as a prey item and provide them with refugia in their burrows. Further investigation of this relationship needs to be determined.

Conclusions

The role that Ozark pocket gophers play in the ecosystem of Izard County cannot be determined at this time. Although we did not have a reference site for comparison (i.e., habitat with pocket gophers vs. habitat lacking pocket gophers), this preliminary study suggested that burrow associates utilize pocket gopher burrows and mounds. The number and extent to which associate species rely on the pocket gophers needs to be determined through both experimental and long term studies. If the Ozark pocket gophers effect on the ecosystem is disproportionately large relative to its abundance then it may in fact be a keystone species (Power et al. 1996).

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Ants of Arkansas Post National Memorial: How and Where Collected

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Abstract

A knowledge of the fauna of natural areas is necessary for their sustainable management. Thus, intensive ant sampling over multiple years was conducted at Arkansas Post National Memorial in southeastern Arkansas. Our collecting techniques included: pitfalls; leaf litter sifting with Berlese extraction; breaking into twigs, branches, and coarse woody debris located on the ground; baiting tree trunks with peanut butter; and general hand collecting. Ants were collected from diverse habitats, including: open mowed-grass, mowed-grass under hardwood trees, unmowed tall-grass and weeds, and numerous forest types. A total of 43 species in 25 genera and 6 subfamilies were identified. The number of species discovered varied by sampling technique: leaf litter extraction collected 28, wood breaking 29, tree baiting 9, hand collecting 25, and pitfalls 35. Two-way hierarchical cluster analysis of ant species against sampled habitats showed that 5 species were almost ubiquitous, while 9 species were present in many of the forested habitats, and 29 other species were much less common. The analysis also showed that successionally "older" forested habitats usually had richer ant communities than successionally "younger" ones, although there were several important exceptions. Additionally, mowed areas without trees supported the fewest ant species, while mowed areas with overhead trees supported more species.

Introduction

Biological inventories are a central element of natural science. They provide the essential information needed for meaningful resource management or conservation biology. Inventories that use structured sampling (i.e. randomizations and repetitions) permit statistical characterization of different spatiotemporal units, like habitats or seasons. Structured sampling uses a variety of methods that emphasize finding many species, but is also quantitative in terms of capture per unit area or time. For structured sampling, relative abundances of focal taxa over space and time are usually more important than absolute numbers of individual species.

The ant literature is filled with articles on the ants of specific locations, for example the Ants of Arkansas (Warren and Rouse 1969). Typically, the methods for a study are provided in detail to help understand the species amassed, or perhaps what might have been missed. As a way of improving on the collecting process, the book, *Ants: Standard Methods for Measuring and Monitoring Biodiversity* (Agosti et al. 2000), was produced. In Chapter 9, Bestelmeyer et al. (2000) detail many of the best collecting procedures developed over the years, their logic, pros and cons, and usefulness of the data collected.

Social insects like ants create a unique sampling problem in that the numbers of individuals collected is often a function of multiple factors: how close sampling is conducted relative to the location of a colony; whether an entire colony may be collected; when the substrate is sampled; how effective a species might be at recruiting workers to baits; or how effective a species might be at defending baits from competitors. Another complication to sampling is that ants occupy many different niches in the landscape. Some species are arboreal and thus are encountered only when they fall off the trees and shrubs patrolled. Many ant species forage and nest in the ground while others can be found only in leaf litter. In addition to spatial separation, ants are also temporally separated, some being diurnal, crepuscular, and/or nocturnal (Hölldobler and Wilson 1990).

Quality of the habitat is likely the most important factor in determining the ant species present (Hölldobler and Wilson 1990). In addition, the advance of forest succession is usually associated with improved ant community richness (Carvalho and Vasconcelos 1999, Maeto and Sato 2004, Osorio-Perez et al. 2007, Silva et al. 2007) because of increasing accumulations and diversity of course woody debris (Grove 2002, Ulyshen 2004, Vanderwel 2006), and the increasing complexity of the soil and litter (Kaspari 1996, Oliver et al. 2000), and vegetation structure (Oliver et al. 2000). Consequently, we expected successionally "older" forested sites to support more ant species than successionally "younger" ones.

The aim of this study was to describe the advantages and disadvantages of the collecting methods and to ascertain the species habitat

relationships of the ant community at the Arkansas Post National Memorial (APNM). Understanding habitat preferences should help the National Park Service be aware of how their management of APNM affects native ants.

Methods

Study Site

APNM is an historical park managed by the National Park Service, and is located 20 km northeast of Dumas, Arkansas County, Arkansas. It is a peninsula bounded on its southeastern tip by an inlet from the Arkansas River (Fig. 1). APNM has a total land area of about 114 ha. Within APNM there are 5 general land cover types; although most cover consists of oak forests mixed with other hardwoods and some conifers. From the general cover types at APNM, 10 stand pairs were selected for ant sampling to provide contrasting successionally "younger" and "older" stands of vegetation that included a separating ecotone (the boundary between two stands or vegetation types). The first stand of the pair is presumed to be "successionally younger" than the second. This successional classification is based on a realization that for the tree species represented in this study, oaks are typically considered late successional species, and conifers, sweetgum (*Liquidambar styraciflua*), and black locust (*Robinia pseudoacacia*) more early successional species (see discussions of successional patterns in Oosting 1956, Bowling and Kellison 1983, and Oliver and Larson 1996, and tree ecological characteristics in Burns and Honkala 1990). For use in the results, abbreviations of the stand types are shown as follows with each stand of a pair being linked using a suffix number:

1. Oak prescribed burned 12 year ago (Oakburn1) vs. unburned oak (Oakubur1)
2. Young sweetgum (YSwtgum2) vs. oak (Oak-2)
3. Old sweetgum (OSwtgum3) vs. oak (Oak-3)
4. Cedar (Cedar-4) vs. oak (Oak-4)
5. Tall grass (Tgrass-5) vs. black locust (Locust-5)
6. Pine (Pine-6) vs. oak (Oak-6)
7. Mowed without trees (Mowed-7) vs. mixed sweetgum (Swtgum-7)
8. Mowed without trees (Mowed-8) vs. tall grass (Tgrass-8)
9. Mowed with trees (Mowed-9) vs. mixed oak (MOak-9)
10. Mowed with trees (Mowed-10) vs. oak (Oak-10)

The stands were characterized by their overstory tree vegetation. All forested sites have a midstory of winged elm (*Ulmus alata*). Oak stands are mostly water oak (*Quercus nigra*), willow oak (*Q. phellos*), and cherrybark oak (*Q. pagoda*). Mixed oak stands additionally have winged elm and sweetgum**.** Sweetgum and mixed sweetgum stands are dominated by sweetgum, but also include some oaks. There were 3 small unique stands: eastern red cedar (*Juniperus virginiana*), loblolly pine (*Pinus taeda*), and black locust. The lone tall grass stand is dominated by Bahia grass (*Paspalum notatum*), blackberry (*Rubus sp*.), and goldenrod (*Solidago spp*.). All mowed areas are dominated by bermuda grass (*Cynodon dactylon*), and the mowed areas with trees have scattered post oak (*Q. stellata*) and pecan (*Carya illinoinensis*). Details of the overstory, midstory, and understory vegetation on these sites can be obtained from General (2007).

Figure 1. Location of numbered collecting sites at Arkansas Post National Memorial.

Sampling transects were designed to extend from one stand type, through an ecotone, and into the adjoining stand type. The ecotones were typically sharply defined, such as the boundary between a mowed area and a forested stand or between pine and oak stands, but an ecotone may be indistinct in the case of the transition between burned and unburned stands. Figure 1 presents a map of APNM with the locations of the 10 study sites for the stand pairs listed above.

Sampling Methods

The ant community was sampled over 2 years and it was sampled differently each year. Pitfall traps were used in 2005 and plot sampling in 2006. Details of the sampling methods are described in General and Thompson (2007). In short, pitfalls sampled the community once in June, July, August, and September.

Pitfalls were plastic vials partially filled with propylene glycol and inserted into a drilled hole so the lip of the vial was level with the ground, and were retrieved after 72 hours. Plot sampling was conducted in each stand of a pair in subplots where ants were collected using leaf-litter extraction, wood breaking, tree-trunk baiting, and visual searching. The species list generated by this sampling is a composite assemblage from these techniques.

Ant Identification

Specimens were identified to species using the most appropriate keys (Bolton 1994, 2000; Bolton et al. 2007; Buren 1968; Creighton 1950; DuBois 1986; Johnson 1988; MacGown 2006; MacKay 1993, 2000; Trager 1984, 1991; Wilson 2003). Problematic specimens and many species determinations were checked and verified by Stefan Cover of the Museum of Comparative Zoology (MCZ) at Harvard University. The Arkansas ant list of Warren and Rouse (1969) has been updated based on the ants collected in this study (General and Thompson 2007). Voucher specimens were deposited with the Arthropod Museum of the University of Arkansas at Fayetteville and the MCZ at Harvard University.

Data Analysis

Ants live in colonies of varying sizes and their distributions are spatially and behaviorally clumped (Longino 2000). Thus, it was necessary to convert our ant abundance data into presence/absence data. Within each stand, species from the 2005 pitfall collections were pooled with those from the 2006 plot collections to generate the presence/absence data set.

We removed only 1 species from the species-stand data set; a single specimen of *Aphaenogaster fulva* collected from the site 10 ecotone was eliminated because the ecotone did not represent a single stand type. Although rare species can cause noise when included in some analyses (McCune and Grace 2002), our objective was to graphically show where all species were collected and to concurrently show possible habitat and species groupings; thus we did not remove any additional rare species. Accordingly, we analyzed 43 species within 20 stands. Before running the analysis, we relativized the raw presence/absence data using the "Information Function of Ubiquity" procedure in PCORD 5.0 (McCune and Mefford 1999, p. 60). This procedure gives less weight to very common and very rare species, and gives more weight to species occurring in half the samples, those that provide the maximum information content according to information theory (Pierce 1980). Additionally, in an attempt to provide a better graphical presentation for species groups, we tried multiple linking methods and distance measures for the 2-way cluster analysis procedure used in PCORD. We ended up using the flexible-beta linking method (beta = -0.25), and the Jaccard distance measure, as recommended by Gotelli and Ellison (2004) for incidence data**.** The resulting dendrogram provides a 2-dimensional picture of the combined relationships of stands among ant species and ant species within stands. Stands were depicted in the dendrogram in rows and species in columns. Within a dendrogram, cluster "breaks" were on a sliding scale with a value of 100 being most similar and 0 being very dissimilar. Natural groups have longer stems in the dendrogram, and very divergent groups were typically linked where the information remaining scale shows zero.

Results

More than 50,000 individual ants were collected in this study, representing a total of 43 species in 25 genera and 6 subfamilies. Table 1 shows the species found at APNM and the sampling methods that collected them. The number of species discovered varied by sampling technique: pitfalls collected 35, wood breaking 29, leaf litter extraction 28, hand collecting 25, and tree baiting 9. Six species were collected only by pitfalls, 3 species were collected only by leaf litter extraction, and 1 species each was collected only by wood breaking and by hand collecting. Tree baiting collected no unique species. This shows that although pitfall trapping was effective in collecting 35 species, it missed 8 species. In contrast, the plot sampling, which in combination resulted in a total of 38 species, missed 5 species.

The 2-way hierarchical cluster analysis (Fig. 2) organized the ant species into a dendrogram with ant species in columns and stands in rows. The species were oriented with the ubiquitous species on the right and moving left toward the less common species. Based on the ants present, 3 groups of stands were identified (A, B and C in Fig. 2). Group A represented the 2 mowed stands without overhead trees. Group B represented the forested stands with greater species richness. These included the oak stands that were assumed to be successionally "older", and where the forest floor was dominated by leaf litter from the overstory. Group C represented stands with lower ant species richness and included diverse habitats like the "open" sites of mowed grass with trees, the 2 tall grass and weeds sites, plus 5 forested stands. The "open"

Table 1. Ant species collected at Arkansas Post National Memorial by sampling method.

	Subfamily Dolichoderinae	Pitfall	Wood	Litter	Trees	Hand
1	*Forelius pruinosus*	X				
2	*Tapinoma sessile*	X				
	Subfamily Formicinae					
1	*Brachymyrmex depilis*	X		X		
2	*Camponotus americanus*	X				X
3	*Camponotus castaneus*	X	X			
4	*Camponotus discolor*	X	X			X
5	*Camponotus pennsylvanicus*	X	X	X		X
6	*Camponotus pylartes*		X		X	X
7	*Camponotus snellingi*		X			X
8	*Formica pallidefulva*	X	X			X
9	*Lasius alienus*	X	X	X		X
10	*Paratrechina terricola*	X	X	X	X	
11	*Prenolepis imparis*	X	X			X
	Subfamily Myrmicinae					
1	*Aphaenogaster fulva*	X				
2	*Aphaenogaster lamellidens*	X	X	X	X	X
3	*Aphaenogaster texana*	X	X	X		X
4	*Crematogaster ashmeadi*	X	X	X	X	X
5	*Crematogaster atkinsoni*	X				
6	*Crematogaster laeviuscula*		X	X	X	X
7	*Crematogaster lineolata*	X	X	X	X	X
8	*Crematogaster minutissima*	X		X		
9	*Crematogaster missuriensis*			X		
10	*Monomorium minimum*	X	X	X	X	X
11	*Myrmecina americana*	X	X	X		X
12	*Myrmica punctiventris*	X	X	X		X
13	*Pheidole bicarinata*	X	X	X		X
14	*Pheidole dentata*	X	X	X	X	X
15	*Pheidole dentigula*			X		
16	*Pheidole pilifera*	X				
17	*Pheidole tysoni*	X	X	X		
18	*Protomognathus americanus*		X			
19	*Pyramica clypeata*	X	X	X		X
20	*Pyramica ornata*		X	X		
21	*Solenopsis invicta*	X	X			X
22	*Solenopsis molesta*	X	X	X		X
23	*Strumigenys louisianae*	X		X		X
24	*Temnothorax curvispinosus*	X	X	X	X	X
25	*Temnothorax pergandei*	X	X	X		X
26	*Temnothorax schaumii*	X				
	Subfamily Ponerinae					
1	*Hypoponera opacior*	X	X	X		
2	*Ponera pennsylvanica*	X	X	X		
	Subfamily Proceratiinae					
1	*Discothyrea testacea*			X		
2	*Proceratium pergandei*	X		X		
	Subfamily Pseudomyrmecinae					
1	*Pseudomyrmex pallidus*					X
	TOTAL SPECIES	35	29	28	9	25

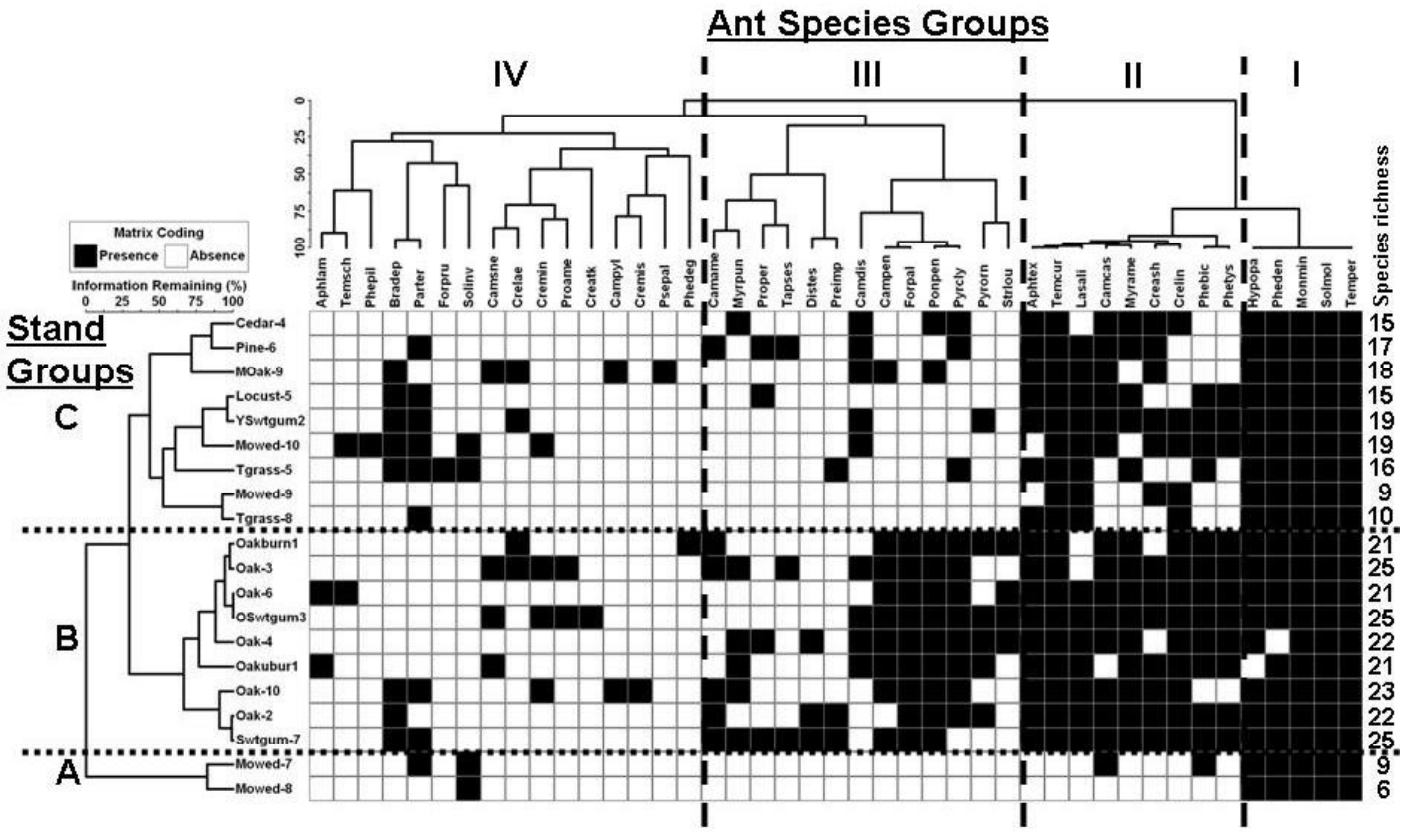

Figure 2. Dendrogram providing a 2-dimensional picture of the combined relationships among stands (rows) and ant species (columns) at Arkansas Post National Memorial. See methods for stand descriptions. Three stand groups were identified: Group A representing mowed sites without trees, Group B successionally "older" stands, and Group C successionally "younger" stands. Four ant species groups were also identified: Group I included the 5 most ubiquitous ants; Group II, 9 common ants that occur in most stands in Groups B and C, but were mostly absent from Group A; Group III, 13 less common ants, that were more species rich in Group B than Group C, and were absent from Group A; and Group IV, 16 ants that were hard to characterize to habitat, and included all 6 rare species (found in only one stand type). Cluster "breaks" within the dendrogram were on a sliding scale with a value of 100 being most similar and 0 being very dissimilar. Natural groups had longer stems in the dendrogram, and very divergent groups were typically linked where the information remaining scale shows zero.

sites had an herbaceous layer dominated by grasses. The 5 forested sites in Group C actually occurred in 2 subgroups with different forest floors. The locust and young sweetgum stand (YSwtgum2) stand clustered with the "open" sites; the locust stand's ground cover was dominated by Cherokee sedge (*Carex cherokeensis*) and the young sweetgum stand was dominated by blackberry. Ground cover in the 2 conifer stands (cedar and pine) and the mixed oak stand (MOak-9) was dominated by leaf litter from their overstory

The successionally "older" forested habitats that included major oak components had richer ant communities (21 or more species, except MOak-9 with 18) than the successionally "younger" conifer, locust, and young sweetgum stands. However, there were 2 major exceptions in the old sweetgum (OSwtgum3) and mixed sweetgum (Sweetgum-7) stands, both with 25 species each. Although in our scheme sweetgum was considered successionally "younger", it obviously can support a rich diversity of ant species.

The cluster analysis of ant species within stands identified 4 groups (I – IV, Fig. 2). Group I included the 5 most ubiquitous ants. Group II included 9 common ants that occurred in most stands in stand Groups B and C, but were mostly absent from stand Group A. Group III included 13 less common ants that were more species rich in stand Group B than Group C, and were absent from stand Group A. And finally, Group IV included 16 ants that were hard to characterize to habitat, and included all 6 rare species (found in only one stand type). Of note in the species clustering was the linking of *Brachymyrmex depilis* (coded Bradep) with *Paratrechina terricola* (Parter) in species group IV (Fig. 2) with the less common species. Regardless of the clustering methods or relativizations used, these species were typically paired. Although we have no specific biological

information to support this connection, both species have been known to occur in "open" habitats (AntWeb 2008). *Solenopsis invicta* (Solinv), an invasive species also known to prefer open habitats, occurred in many of the mowed and tallgrass sites.

Discussion

How Collected

As a stand alone technique, pitfall trapping collected the most species. Its advantages are that it traps nocturnal ants and is relatively easy to deploy if a trap line has already been set up marking trap locations. Its major drawback is that it takes a considerable amount of time to sort through the trap vials and find and remove ants, especially if the vials have been disturbed by vertebrates while deployed and include lots of soil and debris.

Of the plot techniques, wood breaking worked best. Many colonies were found, which produced many workers and often a queen. This is especially helpful if a species was hard to identify. However, extracting the ants from the wood often took lots of time because each branch or twig had to be dissected. Often a Berlese extractor was used for large nests in rotten wood. Litter sifting worked just as well. It went fairly quickly in the field, but slowed down in the laboratory when a backlog of material awaited the availability of Berlese extractors. Litter from a 1-m^2 quadrant might fill 5 Berlese extractors; so having several dozen Berlese extractors available should help facilitate extraction. Bestelmeyer et al. (2000) recommend a litter extractor called a mini-Winkler sack, but this alternative also takes time to construct. Either way, plenty of space is needed to house litter extractors. Hand collecting was almost as useful as litter extraction in finding new species. It is the method of choice for experienced collectors because they know where to look for rare species, and it involves moving around to productive niches to be effective. Also, for collectors experienced with field identification, there are lots of exhilarating moments when a rare species is discovered. However, if the weather is not suitable for ant activity when at the location, the ants may not be out. With this technique, detailed notes on when and where the ants were collected are required for hand collection results to be meaningful. So collectors must spend considerable time "detailing" specimen labels. Certainly, extra effort and superior techniques usually generate more comprehensive ant inventories (King and Porter 2005).

Where Collected

Based on clustering, it does not appear that the ants "perceived" the stands as we viewed them. Our overstory descriptive characteristic of plant species composition and its corresponding relative successional age did not work all that well. Although the presence of trees appears important to the ants, the characteristics of the ground vegetation also seems to be important to them. We have also sampled soil surface characteristics and other habitat characteristics, but this data has yet to be analyzed relative to ant species presence.

Much has been published about relationships between ants and the environmental features of their habitat (more recent studies include Lassau and Hochuli 2004, Parr et al. 2004, Boulton et al. 2005, Ratchford et al. 2005). As would be expected, relating cause and effect relationships is problematic if the environmental variables measured in a study are not those actually affecting the ant community, but may be correlated with variables that are. When taken as a group, the results of ant-environment studies are often puzzling. Regularly, the use of ant abundance measures confuses these relationships, and in other studies the relationship between vegetation and soil related parameters are not well developed. That is, the soil and site conditions influence the vegetation, and over time, the vegetation in turn influences the nature of the litter, duff, and soils. So, which is more important and what is to be measured? This study was not designed to resolve these issues, but simply to characterize the ants in the sampled habitats.

Of note, all the forested stands have had minimal management over the years and consequently probably have adequate supplies of the coarse woody debris, litter, and structural features preferred (Oliver et al. 2000) by many of the forest inhabiting ant species collected. Of the forested sites, the cedar and black locust stands had very different forest floor characteristics; the cedar stand had lots of bare ground, and the black locust stand had dense sedge cover. Both these stands had the lowest species richness among forested sites, 15 species each. Additionally, APNM is a small peninsula, and the forested areas comprise about 85% of the total land area, hence, the matrix effects of the mowed areas and roads within the park are probably not limiting the movement of ants among these mostly adjoining forested sites.

The fewest ant species occurred in the 2 mowed areas without overhead trees (Group A) (Fig. 2), the tall grass stand (Tgrass-8), and one of the mowed sites with a few overhead oaks (Mowed-9). However, the Mowed-10 stand had 19 species collected (Fig. 2). This mowed area had numerous overstory pecan trees,

plus 1 black walnut (*Juglans nigra*). Pecans are known for maintaining diverse populations of foliage feeding and sap-sucking insects (Texas A&M 2008) that might help sustain via honeydew (Blüthgen et al. 2000) the diverse ant species found on the ground below. Interestingly, the lone open tall-grass stand (one stand sampled twice and identified as Tgrass-5 and Tgrass-8) clustered differently based on where the ants were sampled. This unique stand yielded 10 species when sampled closer to the mowed grass, but 16 species when sampled adjacent to the black locust and other trees along an old fence line on the edge. Evidently the nearness of trees was important to some ants.

Most interesting was the low abundance of *S. invicta* within APNM. *Solenopsis invicta* is a sun-loving ant, but we have found it in many forests showing some disturbance, like canopy gaps from dead or fallen trees. We suspect the absence of *S. invicta* was likely due to the ubiquitous presence of *Monomorium minimum* (Monmin) and *S. molesta* (Solmol) that prey upon young *S. invicta* colonies (Rao and Vinson 2004, Vinson and Rao 2004).

Site 3 (Oak-3 and Old Sweetgum3) was a special location because it had the highest overall species richness of 25 (Fig. 2). Three new state records (General and Thompson 2007) of species were recorded there: *C. atkinsoni* (Creatk) and *Strumigenys louisianae* (Strlou) (in the "younger" Old Sweetgum3), and *Protomognathus americanus* (Proame) (in both Old Sweetgum3 and "older" Oak-3). In addition, 15 new county records of species were recorded from site 3. Both stands had 12 new county records each. Likewise, the mixed sweetgum stand (Sweetgum-7) had 25 species, but it had fewer new state records, only *Discothyrea testacea* (Distes) and *Proceratium pergandei* (Proper), and 11 new county species records.

Conclusions

APNM is habitat to some interesting and important ant species. It is intuitive to think that the different stand types identified at APNM may be offering a variety of habitats to ants. In fact, this study showed that the ants responded to few differences among the forested stands. Unique stands, such as the pine, cedar, and black locust, did not harbor any unique ants. Instead of managing the different forested stands individually, it may be better to manage them as a single complex forest, thus simplifying management.

Mowed areas are important for park visitors by providing space for recreation. The mowed areas without trees are relatively depauperate of ant species, except for the 5 ubiquitous species, the red imported fire ant, and a few other natives. The mowed area with pecan trees, however, harbored forest ants, highlighting the importance of having some large overstory trees in mowed areas.

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Aquatic Macroinvertebrates Collected from Thirty-two Missouri Ozark Streams

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Abstract

A previously reported study of the distribution and status of an endemic dragonfly in Missouri emphasized data collected by aerial netting and examination of specimens housed in the Wilbur Enns Museum of Entomology. Dip net samples were also taken, however, to find naiads of the target species at sites where adults might not have been found and to determine whether there were associated species. Forty-one collections were made in 32 Ozark streams between mid-May and early June 1999-2000. Of the 372 taxa identified, *Psephenus herricki* was the most-frequently associated species. Six of the 32 streams either had not been sampled previously or the results have not been published. Three species (*Paragordius varius, Haliplus confluentus* and *Haliplus deceptus*) are first reports for Missouri.

Introduction

Harp and Trial (2001) discussed the distribution and status of an endemic dragonfly, *Ophiogomphus westfalli* Cook and Daigle, in Missouri and Arkansas. Their emphasis was on the Missouri status, and the data reported were limited to that specific species. While determining its status, however, voucher specimens of all adult Odonata observed at each site were also collected.

These latter data were eventually incorporated into Trial's (2005) Atlas of Missouri Odonata. Further, dip net samples of aquatic macroinvertebrates were taken at nearly all sites, with the intent of identifying additional sites where *O. westfalli* occurred through the collection of its naiads.

The Ozark Plateaus were formed by uplifting, folding and faulting processes 300 mya. They are characterized by rugged, flat-topped mountains, long, deep valleys, steep cliffs and ledges, and clear, spring-fed streams (Robison and Buchanan 1988). They formed as a broad dome around the Saint Francois Mountains.

The purposes of this study are to determine which aquatic macroinvertebrate species characteristically co-occur with *O. westfalli*, to provide additional macroinvertebrate records for some Missouri Ozark streams that have previously been sampled, to report aquatic macroinvertebrate lists for 6 Missouri Ozark streams which either have not been sampled or reported previously, and to document first Missouri records for aquatic macroinvertebrate species.

Materials and Methods

Forty-one samples were collected from 32 Missouri Ozark streams. Collections were made from 22 May-1 July 1999 and 1June-5 July 2000 (Table 1). At each site aquatic invertebrates were collected with a Turtox Indestructible™ dip net for approximately 2 hours. Preservation of specimens was in 70% ethanol. These samples were supplemented at each site by collecting adult Odonata with an aerial net (Harp and Trial 2001).

Taxonomic usage follows Merritt et al. (2008) for aquatic insects and Smith (2001) for other aquatic macroinvertebrates. Common names of crayfishes follow Pflieger (1996), while those of Odonata follow Paulson and Dunkle (1999). Supplemental keys used were those of Poulton and Stewart (1991), Moulton and Stewart (1996) and Larson et al. (2000). Voucher specimens are housed in the Wilbur Enns Museum of Entomology, University of Missouri-Columbia.

Stream order ranged from 2nd (e.g. Rogers Cr.) to 5th (Meramec R.). Most of the streams sampled in this study lie within the Salem Plateau subdivision of the Ozark Plateaus, but Big Sugar, Indian and Shoal creeks lie within the Springfield Plateau. Overall, substrates varied from silt to bedrock.

Results and Discussion

Total number of taxa collected was 372 (Table 2). Average richness per site was 47.9 (standard error ± 1.64), with a range of 25-72. In general, species richness increased with stream order. Shoal and Rogers

Table 1. Collecting sites for aquatic macroinvertebrate taxa, Missouri Ozark streams, 1999 (sites 1-21), 2000 (Sites 22-41). (Number of taxa).

Location		Date
1.	South F. Spring R. at jct w/West F., S of St. Hwy. 142, SW¼Sec4, T22N, R8W, Howell Co. (39)	22 May
2.	Bryant Cr. at Co. Hwy PP, 8mi. N Tecumseh, Warren Bridge Access, SE¼Sec16, T23N, R12W, Ozark Co. (38)	22 May
3.	Eleven Pt. R. at Co. Hwy. W, NE¼Sec11, T25N, R7W, Howell Co. (57)	24 May
4.	Rogers Cr. Just N HQ. Bldg., NE¼Sec32, T28N, R2W, Peck Ranch Conservation Area, Carter Co. (27)	25 May
5.	Warm F. Spring R. at St. Hwy. 19,~1mi. N Thayer, NE¼Sec19, T22N, R5W, Oregon Co. (46)	26 May
6.	Roark Cr. at Roark Valley Rd., Branson, Sec22, T23N, R21W, Taney Co. (45)	31 May
7.	Bull Cr. at U.S. Hwy. 160, W edge Walnut Shade, SCSec34, T24N, R21W, Taney Co. (35)	31 May
8.	Swan Cr. at Co. Hwy. AA, ~4mi. NNW Taneyville, CSec1, T24N, R20W, Taney Co. (43)	1 June
9.	James R. at Co. Hwy. O, ~8mi. SW Nixa, SW¼Sec19, T26N, R22W, Stone Co. (54)	2 June
10.	Flat Cr. at Co. Hwy. EE, MDC Lower Flat Cr. Access, SE¼Sec27, T24N, R25W, Barry Co. (55)	3 June
11.	Roaring R., Roaring R. Conservation Area, Co. Hwy. F, SE¼Sec36, T22N, R27W, Barry Co. (37)	3 June
12.	Bryant Cr. at St. Hwy. 95, ~16mi. NNE Gainesville, SW¼Sec2, T24N, R13W, Ozark Co. (40)	5 June
13.	Beaver Cr. at St. Hwy. 76, Bradleyville, WCSec11, T24N, R18W, Taney Co. (39)	5 June
14.	Big Sugar Cr. at St. Hwy. 90, 14mi. E Pineville, NE¼Sec2, T21N, R30W, McDonald Co. (33)	14 June
15.	Indian Cr. at St. Hwy. 76, SE edge Anderson, NE¼Sec12, T22N, R32W, McDonald Co. (53)	14 June
16.	Shoal Cr. at MDC Jolly Access, NE¼Sec15, T25N, R29W, Newton Co. (39)	15 June
17.	Shoal Cr. at MDC Cherry Corner Access (St. Hwy. 59 4mi S Diamond), WCSec34, T26N, R31W, Newton Co. (25)	15 June
18.	Spring R. at St. Hwy. 97, 2mi. N Stotts City, jct. Sec13/14, T28N, R28W, Lawrence Co. (47)	17 June
19.	Little Sac R. at St. Hwy. 215, 3mi. W Morrisville, NW¼Sec29, T32N, R23W, Polk Co. (51)	17 June
20.	Jacks F. R. at St. Hwy. 19, Eminence (MDC Buttin Rock Access), SW¼Sec26, T29N, R4W, Shannon Co. (64)	22 June
21.	West F. Black R. at St. Hwy. 21, Centerville (MDC Centerville Access), SW¼Sec20, T32N, R1E, Reynolds Co. (57)	1 July
22.	Castor R. at Co. Hwy. V, NE¼Sec5, T32N, R8E, Madison Co. (51)	1 June
23.	Meramec R., Meramec R. State Park picnic area, Sec5, T40N, R1W, Franklin Co. (50)	2 June
24.	St. Francis R. at Co. Hwy. 302, 3.7mi. W Coldwater (MDC Coldwater Access), SW¼Sec2, T30N, R5E, Wayne Co. (64)	6 June
25.	St. Francis R. at Co. Hwy. C, jct. Sec10/11, T32N, R5E, Madison Co. (44)	7 June
26.	Twelvemile Cr. at Co. Hwy. C, 12.5mi. W Fredericktown, SE¼Sec13, T31N, R5E, Madison Co. (43)	7 June
27.	St. Francis R. at Co. Hwy. H (Syenite), 5mi. S Farmington, NE¼Sec6, T34N, R6E, St. Francois Co. (48)	8 June
28.	St. Francis R. at Millstream Gardens Conservation Area, SE¼Sec3, T33N, R5E, Madison Co. (68)	8 June
29.	Black R. at Co. Rd. 2 (MDC Lesterville Access), SE¼Sec28, T32N, R2E, Reynolds Co. (51)	9 June
30.	Big Piney R. at St. Hwy. 32, 8mi. W Licking, NW¼Sec12, T32N, R10W, Texas Co. (49)	15 June
31.	North F. White R. At jct. St. Hwy. 14/181, SE¼Sec28, T25N, R11W, Douglas Co. (56)	15 June
32.	Osage F. Gasconade R. at St. Hwy. 32, ~15mi. E Lebanon (MDC Drynob Access), NE¼Sec27, T34N, R14W, Laclede Co. (47)	22 June
33.	Osage F. Gasconade R. 8mi. E Lebanon (MDC Hull Ford Access), SE¼Sec5, T34N, R14W, Laclede Co. (65)	22 June
34.	Gasconade R. at Dawn Rd. (MDC Anna M. Adams Access), NE¼Sec26, T34N, R13W, Laclede Co. (54)	23 June
35.	Gasconade R. ~ 0.5mi downstream of MDC Schlicht Springs Access, jct. Sec28/29, T37N, R12W, Pulaski Co. (34)	23 June
36.	Roubidoux Cr. at N edge Waynesville (MDC Roubidoux Cr. Conservation Area), SW¼Sec24, T36N, R12W, Pulaski Co. (45)	29 June
37.	Big Piney R. at Co. Hwy. J, ~0.3mi. N of its jct. w/Co. Hwy. M, SW¼Sec10, T35N, R10W, Phelps Co. (48)	29 June
38.	Bourbeuse R. ~9mi. S Owensville (1mi upstream of St. Hwy. 19 bridge), NW¼Sec2, T40N, R5W, Gasconade Co. (72)	3 July
39.	Bourbeuse R. at Co. Hwy. EE, 9mi.S Owensville (MDC Mint Spring Access), NE¼Sec13, T40N, R6W, Gasconade Co. (53)	4 July
40.	Big R. at Co. Hwy. H (MDC Merrill Horse Access), NE¼Sec32, T40N, R3E, Jefferson Co. (50)	5 July
41.	Big R. 2.5mi. W Desloge (MDC Leadwood Access), NE¼Sec3, T36N, R4E, St. Francois Co. (46)	5 July

creeks, the smallest creeks sampled, had 25 and 27 taxa, respectively Table 1). The low stream order of Rogers Creek was reflected in that 8 of its 27 taxa were reported from this site only (Table 2). The most commonly occurring taxa (30+ sites) included *Hyalella, Caenis, Isonychia* and *Tricorythodes* (Table 2).

Associated species

Six taxa were collected more than 50% if the time with *O. westfalli, Psephenus herricki* and *Perlesta shubuta* being the most frequent (Table 3). Those species most often found with this dragonfly likewise frequent streams with clear water, moderate current and well-defined riffles. Substrate typically will include

sand and gravel, and there will be no obvious organic overload. While *O. westfalli* is endemic to the Interior Highlands, none of the 6 associated species are. The relationship is apparently limited to a kindred requirement for the relatively healthy habitat described above.

First reports for 6 streams

Of the 32 streams sampled, 6 (South Fork Spring River, Rogers Creek, Warm Fork Spring River, Twelvemile Creek, Roubidoux Creek and Bourbeuse River) either have not been sampled previously, or results of those samples have never been published (Randy Sarver, Mo. Dept. Nat. Res., pers. comm.). This fact was not discovered until late in the study.

In general, streams were chosen because of stream order and to provide a broad coverage of all stream basins in the Missouri Ozarks. The 6 previously unstudied streams were chosen specifically for a variety of reasons. South Fork of Spring River was chosen because *O. westfalli* was known to inhabit this stream along much of its Arkansas portion. Rogers Creek was chosen because it is a protected stream in the Peck Ranch Conservation Area. Roark Creek is an example of a relatively heavily altered stream, as it courses through Branson. Twelvemile Creek was chosen for it size, Roubidoux Creek because of the heavy influence by springs, and Bourbeuse River because of its position on the northern edge of the Salem Plateau, which may explain its having a somewhat heavier silt load that the other streams sampled. No *O. westfalli* were reported from any of these streams (Harp and Trial 2001).

The species richness of the 6 streams ranged from 27-72, with an average of 46.3 (standard error ±5.22). The aquatic macroinvertebrates typified those of other Ozark streams of similar size. The lists for these streams provide baseline data for subsequent research.

First records for Missouri

One specimen each of *Paragordius varius* was collected from the Meramec and St. Francis rivers (Table 2). This species has been reported from several contiguous states, so our records fill in a gap in its known distribution (Schmidt-Rhaesa et al. 2003). As with all horsehair worms, this species is a pseudocoelomate in which the adult is free-living, typically in an aquatic habitat, while the larva is a parasite of insects. The juveniles of this particular species have been reported to parasitize some mayflies (*Baetis, Leptophlebia, Ephemerella*), Heteroptera (*Sigara*), Trichoptera (*Brachycentrus*) and Diptera (*Simulium*) (Schmidt-Rhaesa et al. 2003).

Two specimens of *Haliplus confluentus* Roberts were collected from the West Fork of Black River near Centerville. The species has been reported from Florida, Georgia, South Carolina and Virginia (Matta 1976), and this record extends the known range considerably to the west.

One specimen each of *Haliplus deceptus* Matheson was collected from Bryant Creek near Tecumseh and the West Fork of Black River at Centerville. This species has been reported from Colorado, Kansas, New Mexico, Oklahoma, Texas and Wyoming (Durfee et al. 2005) thus its known range is extended to the east.

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Table 2. Distribution of aquatic macroinvertebrate taxa among the 32 Ozark streams sampled.

Scientific Name	Common Name	Location (Table 1)
PLATYHELMINTHES	Unsegmented flatworms	
Class Turbellaria	Turbellarians	
Order Tricladida	Triclad turbellarians	
Planariidae	Planarians	14
Cura formanii	Planarian	27,28,30,34,38,40
Dugesia tigrina	Planarian	32
NEMATOMORPHA	Horsehair worms	
Class Gordioidea		
Chordodidae	Horsehair worm	
Chordodes morgani	Horsehair worm	37
Gordiidae	Horsehair worm	
Gordius robustus	Horsehair worm	1
Family Parachordodidae	Horsehair worm	
*Paragordius varius**	Horsehair worm	23,24
ANNELLIDA	Segmented round worms	
Class Oligochaeta	Oligochaetes	
Naididae	Aquatic earthworm	6
Lumbriculidae	Aquatic earthworm	5,7,8,10,11,14,16,17,22,23,24, 26,31,32,33,34,36,38,39,40,41
Class Hirudinea	Leeches	
Order Rhynchobdellida	Rhynchobdellid leeches	
Erpobdellidae	Erpobdellid leeches	22,33,34
Erpobdella sp.?	Erpobdellid leech	17,19
Mooreobdella	Erpobdellid leech	9
Glossiphoniidae	Glossiphoniid leeches	
Helobdella	Glossiphoniid leech	24,38,39
Placobdella	Glossiphoniid leech	3,7,9,18,19,27,36
Placobdella papillifera?	Glossiphoniid leech	20
MOLLUSCA		
Class Pelecypoda	Clams, mussels (Bivalves)	
Unionoida	Unionoid mussels	
Unionidae	Freshwater mussels	
Lampsilis reevesiana	Broken-rays mussel	7
Veneroida	Veneroid mussels	
Corbiculidae	Asiatic clam	
Corbicula fluminea	Asiatic clam	12

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
ARTHROPODA	Arthropods	
Hydracarina	Water mites	22,24,25,38
Class Crustacea	Crustaceans	
Order Isopoda	Isopods	
Asellidae	Sow bug or pill bug	
Caecidotea	Sow bug	11,21,23,34,36
Lirceus	Sow bug	5,9,10,14,16,17,18,28,36
Lirceolus?	Sow bug	17
Order Amphipoda	Sideswimmers or scuds	
Crangonyctidae	Sideswimmers or scuds	
Allocrangonyx	Sideswimmer	7
Crangonyx	Sideswimmer	15,21,36,40
Synurella	Sideswimmer	5,9,17
Gammaridae	Sideswimmers or scuds	
Gammarus	Sideswimmer	4,23
Gammarus bousfieldi?	Sideswimmer	18
Gammarus minus	Sideswimmer	11
Gammarus pseudolimnaeus	Sideswimmer	16
Talitridae	Sideswimmers or scuds	
Hyalella azteca	Sideswimmer	1,2,3,9,10,11,12,13,14,15,16,18, 20,21,24,25, 26,27,28,29,30,31,33, 34,35,36,37,38,39,40,41
Cambaridae	Crayfishes	
Orconectes	Crayfish	18,24,29,30,33,34,36,37,39,41
Orconectes luteus	Golden crayfish	1,8,10,13,14,15,16,17,18,23,32
Orconectes ozarkae	Ozark crayfish	2
Orconectes virilis	Northern crayfish	5,9
Class Insecta	Insects	
Order Collembola	Springtails	
Poduridae	Podurid springtails	
Podura aquatica	Podurid springtail	38
Isotomidae	Isotomid springtails	
Isotomurus	Isotomid springtail	35
Sminthuridae	Sminthurid springtails	
Sminthurinus	Sminthurid springtail	27
Order Ephemeroptera	Mayflies	
Baetidae	Baetid mayfly	5
Baetis	Baetid mayfly	2,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,20, 21,24,28,29,31,34,36,37,38,41
Callibaetis	Baetid mayfly	33,39,40
Procloeon rubropictum	Baetid mayfly	38
Caenidae	Caenid mayfly	
Caenis	Caenid mayfly	1,2,3,6,7,8,9,10,11,12,13,14,15,18,19,20,21, 22,23,24,25,26,27,29,31,33,34,37,38,39,40,41
Ephemerellidae	Ephemerellid mayflies	
Attenella attenuata	Ephemerelid mayfly	12,29
Ephemerella invaria	Ephemerellid mayfly	1
Eurylophella aestiva?	Ephemerellid mayfly	6
Eurylophella bicolor	Ephemerellid mayfly	2,5,11,13,14,15
Eurylophella enoensis	Ephemerellid mayfly	1,2,3,4,5,7,8,9,10,11,12,13,14, 15,16,20,22,23,24,26,29,30,31
Serratella deficiens	Ephemerellid mayfly	20,30,37
Serratella serratoides	Ephemerellid mayfly	28
Ephemeridae	Burrowing mayflies	
Ephemera simulans	Burrowing mayfly	5,9,37
Ephemera guttulata	Burrowing mayfly	38
Hexagenia atrocaudata	Burrowing mayfly	2,12,20,31,36
Hexagenia limbata	Burrowing mayfly	5,9,15,18,25,37,40
Heptageniidae	Heptageniid mayflies	
Leucrocuta	Heptageniid mayfly	18,19
Nixe	Heptageniid mayfly	8,10,11,15,18

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
Rhithrogena pellucida	Heptageniid mayfly	8,10
Stenacron interpunctatum	Heptageniid mayfly	1,5,7,9,10,11,15,16,18,19,20,22,23 ,33,34,36,37,38,39
Maccaffertium exiguum	Heptageniid mayfly	10,33
Maccaffertium mediopunctatum	Heptageniid mayfly	1,5,7,8,9,10,12,14,15,19,20,22,24,25,26,30,31,32,33, 34,37,38,39,41
Maccaffertium modestumestum	Heptageniid mayfly	16,18
Maccaffertium pulchellum	Heptageniid mayfly	15,23,25,28,32,33,37,38,39
Maccaffertium terminatum	Heptageniid mayfly	3,5,6,7,9,11,12,15,20,22,24,25,26,27,28,29,31,33, 34,37,38,41
Stenonema femoratum	Heptageniid mayfly	3,5,6,8,13,14,15,19,20,21,22,26,28,34,38,39
Isonychiidae	Isonychiid mayflies	
Isonychia	Isonychiid mayfly	1,2,3,5,7,8,9,10,11,12,13,14,15,16,17,19,20,21,22, 23,24,25,26,27,28,29,30,31,32,33,34,37,38,39,41
Leptophlebiidae	Leptophlebiid mayflies	39
Choroterpes basalis	Leptophlebiid mayfly	6,8,15
Leptophlebia	Leptophlebiid mayfly	34
Paraleptophlebia guttata	Leptophlebiid mayfly	7,10,11
Paraleptophlebia mollis	Leptophlebiid mayfly	6,11,20
Polymitarcyidae	Polymitarcyid mayflies	
Ephoron album	Polymitarcyid mayfly	17,18,19
Potamanthidae	Burrowing mayflies	
Anthopotamus myops	Burrowing mayfly	5,13
Anthopotamus neglectus	Burrowing mayfly	29,33,34,37
Anthopotamus verticis	Burrowing mayfly	9,23,33
Leptohyphidae	Leptohyphid mayflies	
Tricorythodes	Leptohyphid mayfly	3,5,6,8,9,10,11,12,13,14,15,16,18,19,20,21,22,23, 24,25,26,27,28,29,30,31,33,34,36,37,38,39,40,41
Order Odonata	Dragonflies, damselflies	
Calopterygidae	Broad-winged damsels	
Calopteryx maculata	Ebony jewelwing	1,2,3,4,5,7,11,14,16,17,18,20,21,22,24,27,29,30,31, 33,35,36,37,39,40,41
Hetaerina americana	American rubyspot	9,10,15,17,19,21,22,23,24,25,27,28,29,30,31,33,34, 35,37,38,39,40,41
Lestidae	Spreadwing damsels	
Lestes disjunctus	Common spreadwing	18
Lestes inaequalis	Elegant spreadwing	3,35
Coenagrionidae	Pond damsels	
Argia	Dancer	7,8,9,30
Argia apicalis	Blue-fronted dancer	14,18,19,20,23,25,34,35,38,39,40
Argia fumipennis violacea	Variable dancer	1,6,20,22,23,26,31,33,36,39,41
Argia moesta	Powdered dancer	1,2,6,14,17,19,20,21,22,24,25,27,29,30,31,33,34, 35,37,38,39,40,41
Argia plana	Springwater dancer	3,6
Argia sedula	Blue-ringed dancer	1,19,23,24,27,28,31,33,34,35,36,37,38,39,40,41
Argia tibialis	Blue-tipped dancer	1,13,17,19,23,24,25,27,30,31,33,34,37,38,39
Argia translata	Dusky dancer	21,25,31,37,38,39
Chromagrion conditum	Openwing damsel	1
Enallagma	Bluet	1,2,3,7,9,10,12,13,23,26,28,31,32
Enallagma basidens	Double-striped bluet	20,22,24,25,33,34,40
Enallagma civile	Familiar bluet	6
Enallagma divagans	Turquoise bluet	1,21
Enallagma exsulans	Stream bluet	1,2,5,6,17,18,19,20,21,22,24,25,27,29, 30,31,33,34,35,36,37,38,39,40,41
Enallagma geminatum	Skimming bluet	25,36
Enallagma signatum	Orange bluet	27,30
Ischnura	Forktail	28,32,35
Ischnura hastata	Citrine forktail	6,18
Ischnura posita	Fragile forktail	1,5,6,15,18,20,22,24,25,27,30,31,33,34,36,37,38,40,41
Ischnura verticalis	Eastern forktail	1,33,36,38

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
Aeshnidae	Darner dragonflies	
Anax junius	Green darner	3,18,34,40,41
Basiaeschna janata	Springtime darner	8,13,22,35,36,37
Boyeria vinosa	Fawn darner	2,5,9,10,12,15,16,20,21,26,28,29,30,31,32,33,34,35,36, 38,39,40,41
Gomphidae	Clubtail dragonfly	
Arigomphus villosipes	Unicorn clubtail	3
Dromogomphus spinosus	Black-shouldered spinyleg	3,6,13,15,17,18,20,24,28,29,31,33,34,35,36,38,40,41
Erpetogomphus designatus	Eastern ringtail	34,38,35
Gomphus	Clubtail	38
Gomphus exilis	Lancet clubtail	22,24,25,26,28
Gomphus graslinellus	Pronghorn clubtail	1,3,5,6,7,10,16,17,18,20,32
Gomphus lineatifrons	Splendid clubtail	30,34
Gomphus ozarkensis	Ozark clubtail	1,7,12,17,20,24,25,28,30,31,34,35,37
Gomphus quadricolor	Rapids clubtail	20
Gomphus vastus	Cobra clubtail	23,35
Hagenius brevistylus	Dragonhunter	5,8,12,21,25,27,29,30,31,32,33,34,36,37,38,40,41
Ophiogomphus westfalli	Westfall's snaketail dragonfly	2,7,8,10,12,13,14,16,20,22,23,30,32,33,35,37
Progomphus obscurus	Common sanddragon	24,26,27,28,29,30,31,37,38,40
Stylogomphus sigmastylus	Western least clubtail	1,6,7,8,9,10,11,12,13,14,15,16,18, 19,20,21,22,23,25,26,29,30,32
Stylurus spiniceps	Arrow clubtail	40
Macromiidae	River cruisers	
Didymops transversa	Stream cruiser	30
Macromia	River cruiser	8,10,23,28,29,31,38
Macromia pacifica	Gilded river cruiser	27
Corduliidae	Emeralds	
Epitheca	Emerald	21
Epitheca cynosura	Common baskettail	24,25,27
Epitheca princeps	Prince baskettail	1,5,24,25,27,33,34,35,38,39
Neurocordulia xanthosoma	Orange shadowdragon	19
Libellulidae	Skimmer dragonflies	
Celithemis fasciata	Banded pennant	39
Dythemis velox	Swift setwing	1
Erythemis simplicicollis	Eastern pondhawk	1,5,15,17,18,19,20,24,25,27,30,33,34,35,36, 37,38,39,40
Libellula cyanea	Eastern spangled skimmer	5,7,22,27,28,36
Libellula incesta	Slaty skimmer	1,20,28,33,34,37,38
Libellula luctuosa	Widow skimmer	1,9,20,24,25,27,30,31,33,34,35,36,37,38,39,40,41
Libellula pulchella	Twelve-spotted skimmer	22
Libellula vibrans	Great blue skimmer	34
Pachydiplax longipennis	Blue dasher	1,5,17,27,28,31,34,36,41
Perithemis tenera	Eastern amberwing	5,18,27,28,33,39
Pantala hymenaea	Spot-winged glider	7
Plathemis lydia	Common whitetail	4,5,7,17,18,25,29,31,34,36,38,40
Symmpetrum	Meadowhawk	39
Sympetrum vicinum	Yellow-legged meadowhawk	33
Tramea lacerata	Black saddlebags	23,25,27
Order Plecoptera	Stoneflies	
Pteronarcyidae	Pteronarcyid stoneflies	
Pteronarcys	Pteronarcyid stonefly	12,30,31,33,36,37
Pteronarcys pictetii ?	Pteronarcyid stonefly	20
Leuctridae	Winter stoneflies	
Zealeuctra	Winter stonefly	8,9,11,20,21,26,29
Nemouridae	Nemourid stoneflies	
Amphinemura delosa?	Nemourid stonefly	2,3,5
Perlidae	Perlid stoneflies	
Acroneuria	Perlid stonefly	6,33,34
Acroneuria evoluta	Perlid stonefly	1,9
Agnetina capitata	Perlid stonefly	9,11
Agnetina flavescens	Perlid stonefly	9,15,24,27,28

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
Neoperla catharae	Perlid stonefly	7,19,39
Neoperla falayah	Perlid stonefly	10,15,22,38
Neoperla harpi	Perlid stonefly	8,15,18,19,20,22,24,25,28
Neoperla osage	Perlid stonefly	15,25,28,34
Perlesta browni	Perlid stonefly	1,2,8,12,15
Perlesta cinctipes	Perlid stonefly	5,6,8,9,17
Perlesta decipiens	Perlid stonefly	3,7,9,10,13,14,18,19,23,27,28
Perlesta shubuta	Perlid stonefly	1,2,7,9,10,12,15,18,19,20,22,26,28,29, 30,31,37
Perlodidae	Perlodid stoneflies	
Isoperla coushatta	Perlodid stonefly	2
Isoperla dicala	Perlodid stonefly	11
Order Hemiptera	True bugs	
Belostomatidae	Electric light bugs	
Belostoma nymph	Electric light bug	23,28,33,38
Belostoma flumineum	Electric light bug	2,17,18,20,24,30,31,32,34,36
Corixidae	Water boatmen	38
Palmacorixa buenoi	Water boatman	4
Sigara grossolineata	Water boatman	15,21
Sigara mathesoni	Water boatman	3,4,5,16
Trichocorixa	Water boatman	1,13
Trichocorixa calva	Water boatman	2,3,16,18,19,20,23,33,39,40
Trichocorixa kanza	Water boatman	7,9,31
Gelastocoridae	Toad bugs	
Gelastocoris oculatus oculatus	Toad bug	1,3,5,6,15,17,23,24,25,28,32,33,35,36,37
Gerridae	Water striders	
Gerris nymph	Water strider	5,15,25,29,40
Aquarius remigis	Water strider	11,16,18,23,30,36
Gerris marginatus	Water strider	23,24,25,27,34,39,41
Gerris nebularis	Water strider	34
Limnoporus canaliculatus	Water strider	29
Metrobates hesperius	Water strider	23,25,28,38
Neogerris hesione	Water strider	8,37
Rheumatobates trulliger	Water strider	19,20,40
Trepobates nymph	Water strider	27,35,38,39
Trepobates knighti	Water strider	24,28,33
Trepobates subnitidus	Water strider	18,20,31
Hebridae	Velvet water bugs	
Hebrus concinnus	Velvet water bug	32
Hebrus consolidus	Velvet water bug	16,26,35
Hydrometridae	Water measurers	
Hydrometra australis (= *martini*)	Water measurer	1,3,5,15,16,20,25,26,28,29,30,32,33,34,35, 36,37
Mesoveliidae	Water treaders	
Mesovelia nymph	Water treader	15,29,40d
Mesovelia mulsanti	Water treader	1,2,6,7,8,9,19,20,22,23,24,25,27,28,30, 31,32,33,34,35,38,39,41
Naucoridae	Creeping water bugs	
Pelocoris nymph	Creeping water bug	35,38
Pelocoris femoratus	Creeping water bug	24,32
Nepidae	Water scorpions	
Nepa apiculata	Water scorpion	16
Ranatra kirkaldyi	Water scorpion	3,21,28,29,32,33,34,35,38,39
Ranatra nigra	Water scorpion	19,20,24,27,35
Notonectidae	Back swimmers	
Notonecta irrorata	Back swimmer	18
Pleidae	Pygmy backswimmers	
Pleid nymph	Pygmy backswimmer	33,41
Neoplea striola	Pygmy backswimmer	2,9,16,17,34,39
Saldidae	Shore bugs	
Pentacora	Shore bug	6
Saldula pallipes	Shore bug	21

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
Veliidae	Small water striders	
Microvelia nymphs	Small water strider	2,14,23,37,41
Microvelia americana	Small water strider	4,5,8,11,15,16,18,19,20,21,22,25,26,27,29,31, 33,34,36,38
Microvelia hinei	Small water strider	24,28,33
Microvelia paludicola	Small water strider	13
Rhagovelia sp.	Broad-shouldered water strider	1,2,3,6,9,10,12
Rhagovelia knighti	Broad-shouldered water strider	15,18,19,21,22,25,26,27,28,29,31,32,33,34, 36,37,40,41
Steinovelia stagnalis	Small water strider	32,34,35,37
Order Megaloptera	Alderflies, dobsonflies, fishflies	
Corydalidae	Dobsonflies, fishflies	
Chauliodes pectinicornis	Fishfly	21,31
Corydalus cornutus	Hellgrammite	1,3,7,8,10,12,13,15,19,20,21,22,23,24,25,28,29,30 31,32,33,37,38,39,41
Nigronia serricornis	Fishfly	8,11,22,26,30
Sialidae	Alderflies	
Sialis	Alderfly	5,6,19,23,24,28,37,38,39
Order Trichoptera	Caddisflies	
Glossosomatidae pupa	Glossosomatid caddisflies	32
Helicopsychidae	Helicopsychid caddisflies	
Helicopsyche pupa	Helicopsychid caddisfly	26,30
Helicopsyche borealis?	Helicopsychid caddisfly	24
Helicopsyche limnella	Helicopsychid caddisfly	3,5,10,16,36
Hydropsychidae	Hydropsychid caddisflies	
Ceratopsyche	Hydropsychid caddisfly	12,13,20,21,22,26,29,30,36,37,41
Ceratopsyche slossonae	Hydropsychid caddisfly	12
Cheumatopsyche	Hyropsychid caddisfly	9,13,14,16,18,19,23,25,26,27,28,29,30,33,37,38,39,41
Hydropsyche	Hydropsychid caddisfly	1,5,8,9,10,16,17,18,19
Hydropsyche scalaris	Hydropsychid caddisfly	24
Potamyia flava	Hydropsychid caddisfly	1,3,5,6,7,8,9,11,12,13,15,17,18,21,22,24,27,31,34,36, 37,38,39,41
Hydroptilidae	Hydroptilid caddisflies	
Hydroptila	Hydroptilid caddisfly	28
Ochrotrichia	Hydroptilid caddisfly	38
Orthotrichia	Hydroptilid caddisfly	40
Paucicalcaria ozarkensis?	Hydroptilid caddisfly	9
Stactobiella?	Hydroptilid caddisfly	40
Leptoceridae	Leptocerid caddisflies	
Nectopsyche	Leptocerid caddisfly	41
Oecetis	Leptocerid caddisfly	23
Oecetis avara?	Letocerid caddisfly	40
Nectopsyche	Leptocerid caddisfly	12,20,24,28,30,40
Triaenodes	Leptocerid caddisfly	29,30,33,36
Limnephilidae	Limnephilid caddisflies	
Platycentropus radiatus	Limnephilid caddisfly	4
Pycnopsyche	Limnephilid caddisfly	4,18
Pseudostenophylax	Limnephilid caddisfly	7
Odontoceridae	Odontocerid caddisflies	
Marilia flexuosa	Odontocerid caddisfly	9,22,26
Philopotamidae	Philopotamid caddisflies	
Chimarra	Philopotamid caddisfly	1,8,10,13,16,22,24,26,27,32,33,38,39,41
Polycentropodidae	Polycentropodid caddisflies	
Polycentropus	Polycentropodid caddisfly	23,31
Psychomyiidae	Psychomyiid caddisflies	
Psychomyia flavida	Psychomyiid caddisfly	20,33
Uenoidae	Uenoid caddisflies	
Neophylax concinnus	Uenoid caddisfly	18
Order Lepidoptera	Butterflies, moths	
Pyralidae	Pyralid moths	
Crambus	Pyralid moth	33
Parapoynx	Pyralid moth	9,10,41

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
Order Coleoptera	Beetles	
Curculionidae	Weevils	
Lixus	Weevil	32,35,36,40,41
Rhinoncus	Weevil	35
Dryopidae	Dryopid riffle beetles	8
Helichus fastigiatus	Dryopid riffle beetle	16,27,38
Helichus lithophilus	Dryopid riffle beetle	7,10,12,13,22,23,24,25,27,28,30,31,32, 33,34,35,36, 37,38,40,41
Dytiscidae	Predaceous diving beetles	
Agabus	Predaceous diving beetle	5
Agabus ambiguous?	Predaceous diving beetle	3
Agabus obliteratus	Predaceous diving beetle	4
Agabus semivittatus	Predaceous diving beetle	23
Agabus subfuscatus	Predaceous diving beetle	4
Bidessonotus inconspicuous	Predaceous diving beetle	4
Celina hubbelli	Predaceous diving beetle	3,6
Coptotomus venustus	Predaceous diving beetle	20,21,27,28,32,34
Cybister fimbriolatus	Predaceous diving beetle	24,28
Graphoderus larva	Predaceous diving beetle	27
Hydroporus sp. 1	Predaceous diving beetle	2,3,5,6,9,12,13,14,15,16,17,18,19,21,23,27, 28,32,33,34,36,38,39,40,41
Hydroporus sp. 2	Predaceous diving beetle	3,5,23,32,39,40
Hydroporus sp. 3	Predaceous diving beetle	40
Hydrovatus pustulatus	Predaceous diving beetle	3
Ilybius biguttulus	Predaceous diving beetle	4
Ilybius incarinatus	Predaceous diving beetle	13,21
Laccophilus larvae	Predaceous diving beetle	24
Laccophilus fasciatus rufus	Predaceous diving beetle	20,40
Laccophilus maculosus maculosus	Predaceous diving beetle	23,31,38,39,40
Laccophilus proximus proximus	Predaceous diving beetle	3,4,18,19
Thermonectus basillaris	Predaceous diving beetle	3
Thermonectus ornaticollis	Predaceous diving beetle	3
Uvarus	Predaceous diving beetle	5
Ancyronyx variegata	Elmid riffle beetle	14,31
Dubiraphia minima	Elmid riffle beetle	2,7,8,10,12,13,18,19,20,21,22,24,25,26,27, 28,29,30, 31,33,37,38,40,41
Dubiraphia vittata	Elmid riffle beetle	14,16,36
Elmidae	Elmid riffle beetles	
Macronychus glabratus	Elmid riffle beetle	9,10,19,23,27,28,29,31,33,37,38,40
Microcylloepus? larva	Elmid riffle beetle	13
Microcylloepus pusillus	Elmid riffle beetle	24,25,28,29
Optioservus larva	Elmid riffle beetle	33,36,37
Optioservus sandersoni	Elmid riffle beetle	2,12,13,15,16,17,18,20,21,22,24,25,26, 29,30,31,36,38
Stenelmis larva	Elmid riffle beetle	5,14,20,23,24,25,29,31,32,33,34,36,37,39,41
Stenelmis beameri	Elmid riffle beetle	7,10,15,18,19,22,32,34
Stenelmis crenata	Elmid riffle beetle	1,9,18,19,27,28,33,38,41
Stenelmis exigua	Elmid riffle beetle	24,25,28,38,39
Stenelmis exilis	Elmid riffle beetle	6,17
Stenelmis lateralis	Elmid riffle beetle	10,15,21,26,32,33
Stenelmis mera	Elmid riffle beetle	8,22,26,33
Stenelmis sandersoni	Elmid riffle beetle	28
Stenelmis sexlineata	Elmid riffle beetle	39
Gyrinidae	Whirligig beetles	
Dineutus larva	Whirligig beetle	21,23,25,38,39,41
Dineutus assimilis	Whirligig beetle	18
Dineutus carolinus	Whirligig beetle	20
Dineutus ciliatus	Whirligig beetle	1
Dineutus discolor	Whirligig beetle	1,13,20,23,25,26,29,31,38,39,40,41

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
Gyretes sinuatus	Whirligig beetle	38,40
Gyrinus larva	Whirligig beetle	1,29,40
Gyrinus analis	Whirligig beetle	3,8,13,20,25
Gyrinus gibber	Whirligig beetle	18
Gyrinus pachysoma	Whirligig beetle	10
Gyrinus woodruffi	Whirligig beetle	20,30,32,33,35
Haliplidae	Crawling water beetles	
*Haliplus confluentus**	Crawling water beetle	21
*Haliplus deceptus**	Crawling water beetle	2,21
Haliplus fasciatus	Crawling water beetle	20
Haliplus triopsis	Crawling water beetle	2,24,29,30,34
Peltodytes dispersus?	Crawling water beetle	24
Peltodytes dunavani	Crawling water beetle	1
Peltodytes duodecempunctatus	Crawling water beetle	3,5,7,10,19,24,32,33,34,35,38,39,40,41
Peltodytes festivus	Crawling water beetle	38,39
Peltodytes lengi	Crawling water beetle	9,23,24,27,32
Peltodytes litoralis	Crawling water beetle	1,2,3,19,23,30,32,34,38,40
Peltodytes muticus	Crawling water beetle	4,19,33,38
Peltodytes sexmaculatus	Crawling water beetle	2,3,10,20,23,24,27,30,33,35
Helophoridae	Water scavenger beetles	
Helophorus linearus	Water scavenger beetle	3,5
Hydrochidae	Water scavenger beetles	
Hydrochus rufipes	Water scavenger beetle	3,27,28,30,32,33,34
Hydrophilidae	Water scavenger beetles	
Anacaena limbata	Water scavenger beetle	16
Anacaena suturalis	Water scavenger beetle	3,27,28
Berosus larva	Water scavenger beetle	33
Berosus fraternus	Water scavenger beetle	34
Berosus infuscatus	Water scavenger beetle	20,28,39
Berosus peregrinus	Water scavenger beetle	2,9,19,21,22,24,27,28,34,39,40,41
Berosus striatus	Water scavenger beetle	21
Derallus altus	Water scavenger beetle	3
Enochrus blatchleyi	Water scavenger beetle	28
Enochrus ochraceus	Water scavenger beetle	3,4,5,10,16,20,21,22,28,30,34,35
Enochrus perplexus	Water scavenger beetle	4
Enochrus pygmaeus nebulosus	Water scavenger beetle	14,17,23,25,27,28,31,32,34,39
Enochrus cinctus	Water scavenger beetle	18,21
Enochrus consortus	Water scavenger beetle	27,33
Enochrus sayi	Water scavenger beetle	6,19,21
Helochares maculicollis	Water scavenger beetle	16,20,31,33
Hydrobiomorpha casta	Water scavenger beetle	23
Laccobius	Water scavenger beetle	14,25
Laccobius minutoides	Water scavenger beetle	24,30,36
Laccobius reflexipennis	Water scavenger beetle	21,22,32
Paracymus	Water scavenger beetle	3,20,22,27,32
Paracymus confluens	Water scavenger beetle	21
Paracymus subcupreus	Water scavenger beetle	20,25
Sperchopsis tessellatus	Water scavenger beetle	23,24,26,37
Tropisternus larva	Water scavenger beetle	1,8,13,14,15,19,20,23,24,25,28,29,30,31,32,33,34,35, 38,39,40,41
Tropisternus blatchleyi modestus	Water scavenger beetle	19
Tropisternus collaris mexicanus	Water scavenger beetle	18,23
Tropisternus c. mexicanus x T. collaris striolatus	Water scavenger beetle	18
Tropisternus c. striolatus	Water scavenger beetle	20,23
Tropisternus glaber	Water scavenger beetle	3,5,19,20,22,27,32,34,38,39,41

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
Tropisternus lateralis nimbatus	Water scavenger beetle	3,20,23
Tropisternus natator	Water scvenger beetle	1,2,3,10,21,23,24,28,30,31,36,40
Lutrochidae	Marsh-loving beetles	
Lutrochus laticeps	Marsh-loving beetle	6,7,8,9,10,12,13,20,21,24,31
Noteridae	Burrowing water beetles	
Hydrocanthus atripennis	Burrowing water beetle	2,3,24
Hydrocanthus oblongus	Burrowing water beetle	3
Psephenidae	Water pennies	
Ectopria nervosa	Water penny	15
Psephenus herricki	Water penny	1,6,7,8,9,10,12,13,14,15,17,22,30,31,32,33,34,37
Scirtidae	Marsh beetles	
Cyphon	Marsh beetle	11,18
Scirtes	Marsh beetle	1,3,5,16,20,21,22,24,30,31,32,33,34,35,36, 37,38
Athericidae	Snipe flies	
Atherix variegata	Snipe fly	15,20,21,22,24,25,26,28,29,37
Ceratopogonidae	No-see-ums	
Ceratopogonid pupa	No-see-um	32
Atrichopogon	No-see-um	6
Bezzia or *Palpomyia*	No-see-um	2,3,21,22,24,25,27,28,29,30,34,35,36,38,39, 40,41
Culicoides	No-see-um	40
Probezzia	No-see-um	1,6,8,9,10,11,25,31,36
Sphaeromias longipennis	No-see-um	18,20,35
Stilobezzia	No-see-um	24
Chironomidae	Bloodworms	
Tanypodinae (not T. Gp.)	Bloodworm	21
Clinotanypus	Bloodworm	4,6,8,24,30,31,38,39,40
Procladius (*Holotanypus*)	Bloodworm	4,6,15,20,38,39,40
Procladius bellus	Bloodworm	38
Ablabesmyia annulata	Bloodworm	40
Ablabesmyia mallochi	Bloodworm	10,13,27,29,31,41
Ablabesmyia rhamphe gp.	Bloodworm	6,38
Conchapelopia	Bloodworm	3
Pentaneura sp. A	Bloodworm	21
Thienemannimyia gp.	Bloodworm	1,6,7,12,14,15,19,21,26,29,36,37
Potthastia gaedia gp.	Bloodworm	21
Sympotthastia	Bloodworm	21
Orthocladiinae	Bloodworm	8,9,20,24,33
Brillia cf *flavifrons*	Bloodworm	5,11
Cardiocladius	Bloodworm	13,26
Cardiocladius cf *obscurus*	Bloodworm	37
Cricotopus / *Orthocladius*	Bloodworm	15
Cricotopus	Bloodworm	2,3,6,11,14,39
Cricotopus bicinctus	Bloodworm	10,11,12,19,28,38,41
Cricotopus trifascia	Bloodworm	9,11
Eukiefferiella	Bloodworm	25
Heterotrissocladius	Bloodworm	4
Nanocladius	Bloodworm	8,25,28
Nanocladius downesi	Bloodworm	30,32,33
Orthocladius	Bloodworm	22
Parametriocnemus	Bloodworm	26,36
Paraphaenocladius	Bloodworm	34
Psectrocladius psilopterus gp	Bloodworm	26
Psectrocladius cf *simulans*	Bloodworm	26
Rheocricotopus cf *robacki*	Bloodworm	26
Tvetenia cf *vitracies*	Bloodworm	28
Chironomus	Bloodworm	1,2,9,12,13,15,19,20,21,22,26,34,38
Cryptochironomus	Bloodworm	7,19,27,39
Cryptotendipes	Bloodworm	40

Table 2. Continued

Scientific Name	Common Name	Location (Table 1)
Dicrotendipes	Bloodworm	3,9,12,14,20,21,29,41
Dicrotendipes modestus/ neomodestus	Bloodworm	6,10,11,13,15,22,26
Endochironomus	Bloodworm	6
Kiefferulus	Bloodwoom	22
Microtendipes pedellus gp.	Bloodworm	5,6,10,11,26,36,37,38
Paratanytarsus	Bloodworm	11,33,38,41
Phaenopsectra	Bloodworm	6,31
Phaenopsectra or *Tribelos*	Bloodworm	11,12,13,38
Paratendipes	Bloodworm	4
Paratendipes albimanus gp.	Bloodworm	36
Polypedilum	Bloodworm	6,30
Polypedilum aviceps	Bloodworm	12,13,14
Polypedilum fallax	Bloodworm	10,20
Polypedilum flavum	Bloodworm	6,7,8,9,10,13,15,16,17,19,22,24,25,27, 28,37,38,39
Polypedilum halterale gp.	Bloodworm	31,38
Polypedilum illinoiense gp.	Bloodworm	2,3,8,9,10,11,12,13,14,15,16,18,19,20,22,24,25,27, 28,29,31,32,33,34,35,37,38, 40,41
Polypedilum scalaerum gp.	Bloodworm	6
Stictochironomus	Bloodworm	11,28
Tribelos cf *jucundum*	Bloodworm	38
Cladotanytarsus	Bloodworm	19
Paratanytarsus	Bloodworm	40
Rheotanytarsus	Bloodworm	19,27,28,29,39
Tanytarsus sp. G or L (Epler)	Bloodworm	20,38,41
Culicidae	Mosquitoes	
Anopheles	Mosquito	34,39
Anopheles punctipennis	Mosquito	16
Dixidae	Dixid midges	
Dixa	Dixid midge	3,4,5
Dixella	Dixid midge	4,29,30
Dolichopodidae	Long-legged flies	35
Muscidae	Muscid flies	
Limnophora	Muscid fly	6
Sciomyzidae	Marsh flies	
Sepedon	Marsh fly	3,4
Simuliidae	Blackflies	
Cnephia	Blackfly	1,3,7,9,11,12,14,15,16,17,18,19,20,21,22,24,25,26,28, 29,30,31,36,37
Metacnephia	Blackfly	10
Simulium	Blackfly	6
Stratiomyidae	Soldier flies	
Stratiomys	Soldier fly	14,20,23,30,31,33,35
Tabanidae	Horseflies, deerflies	
Chrysops	Horsefly	4,10,16
Hybomitra	Horsefly	1,3,12,22,24,30,34,39
Tipulidae	Craneflies	
Hexatoma	Cranefly	7,25,28,36,39
Holorusia	Cranefly	22
Limnophila	Cranefly	33
Limonia	Cranefly	26,35
Pilaria	Cranefly	32
Rhabdomastix?	Cranefly	14
Tipula	Cranefly	1,6,14,21,26,30,33,36

Total Taxa = 372

***New State Record.**

Table 3. Frequency of co-occurrence of the most commonly collected aquatic macroinverebrates with *Ophiogomphus westfalli*.

Taxon	No. of times collected	With *Ophiogomphus*	% Freq.
Psephenus herricki	18	11	61
Perlesta shubuta	17	10	59
Helichus lithophilus	21	12	57
Polypedilum illinoiense gp.	27	15	56
Stylogomphus sigmastylus	17	9	53
Eurylophella enoensis	23	12	52
Stenonema mediopunctatum	25	13	52
Scirtes	18	9	50
Isonychia	35	16	48
Boyeria vinosa	23	11	48
Mesovelia mulsanti	23	11	48
Peltodytes duodecempunctatus	15	7	47
Baetis	27	12	44
Stenonema interpunctatum	18	8	44
Corydalus cornutus	25	11	44
Dubiraphia minima	25	11	44
Caenis	32	13	41
Enallagma	32	13	41
Hydrometra australis	17	7	41
Argia	15	6	40
Cnephia	25	10	40

Insects Inhabiting the Burrows of the Ozark Pocket Gopher in Arkansas

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Abstract

Pocket gopher burrows provide a stable environment for a variety of inquilines; hence this mammal is regarded as a keystone species. Most of the arthropods inhabiting pocket gopher burrows are restricted to this microhabitat. As part of a planned state-wide biotic survey of insects inhabiting this unusual microhabitat, we have focused our initial sampling efforts on the Ozark pocket gopher (*Geomys bursarius ozarkensis*; Geomyidae). In 2004 and 2005, pitfall traps were established in pocket gopher burrows and in 2007 and 2008, nests and associated chambers were excavated. Retrieved samples contained scarab, histerid, and rove beetles, cave crickets and anthomyiid flies. The histerids consisted of five species, one of which is undescribed, and all of which are new state records. A total of five species of scarab beetles were collected and all of these represent new state records. Two species of cave crickets were collected; one appears to be undescribed, and the other is essentially a Great Plains species and represents a considerable range extension. Both crickets are new to Arkansas.

Introduction

Pocket gopher burrows harbor a niche-specific arthropod fauna consisting mainly of beetles, cave crickets and flies (Hubbell and Goff 1939, Hubbell 1940, Ross 1940, 1944a, 1944b, Skelley and Gordon 2001, Skelley and Kovarik 2001, Skelley and Woodruff 1991, Kriska and Katovich 2006, Paulsen 2006). The beetles and flies tend to inhabit the nest and fecal chambers of the pocket gopher while the cave crickets tend to inhabit the burrow runways. Recently, an improved understanding of the distributions of many of these insects has been achieved through the combined sampling efforts of a growing number of biologists. In some cases these surveys focused on insects inhabiting burrows of a particular species or subspecies of pocket gopher while in other instances the surveys were geopolitically bounded. Some of this work has been published, but much of it remains unpublished.

In 2000, Elrod et al. published an intriguing paper describing an isolated subspecies of pocket gopher (*Geomys bursarius ozarkensis*) inhabiting the Ozark Mountains in Arkansas. According to Elrod et al. (2000), this subspecies is more closely related to a subspecies in Missouri (*Geomys bursarius missouriensis*) than to the geographically proximate species *G. breviceps*. Insect sampling from pocket gopher burrows thus far had indicated that there was a correlation between isolated populations of *Geomys* and insects new to science, and all indications were that the same should hold true for the Ozark pocket gopher. Accordingly, we selected Izard County as the starting point for a planned state-wide survey of insects inhabiting pocket gopher burrows in Arkansas. In April of 2004, three pitfall traps were established in pocket gopher burrows next to the White River in Guion, Arkansas. In only two days time, these traps had produced two beetle species and two species of cave crickets, which were all new state records and one species of crickets was new to science. More extensive pitfall sampling was conducted at several different localities the following year, and in 2008, nests and associated chambers of this species were excavated and sampled for the first time for insects. Some of the scarab records that appear in this paper were recently published by Gordon and Skelley (2007). This paper also includes new generic level combinations for the species of scarabs formerly included in the genus *Aphodius*.

Materials and Methods

Pitfall sampling was done during April in 2004 and 2005. Nest/chamber excavations were done during January, February, and March of 2008. Methods used in locating burrows, removing gophers, and pitfall trapping insects are described in detail by Skelley and

Gordon (2001) and Skelley (1992). Radio telemetry was employed to locate nests before subsequent excavation. Methods and live traps used to capture pocket gophers are described in detail in Connior and Risch (2008a). After capture, radio transmitters were implanted (PD-2H, Holohil Systems, Ltd., Carp, Ontario, Canada) subcutaneously in the individuals at the field site (Connior and Risch 2008b). Probable nest sites were located by repeatedly tracking these individual pocket gophers via radio telemetry to a static location inside their burrows. Subsequent excavation of seven of these areas resulted in a nest find, thus validating the reliability of this methodology. In December 2007, latrine chambers that had been pushed above ground during mound building were collected opportunistically when noticed. Insects were gathered from three localities within Izard County. Since all of the areas where the gophers occur are in private hands, the localities chosen for sampling were those for which we were able to obtain permission from the landowner. These localities were as follows:

1) Guion, Hwy. 58 at White River bridge (35°55.55'N; 091°56.85'W)
2) North of Guion, 10 km. N. jct. Rt. 58 & White River bridge (35°58.30'N; 091°52.02'W)
3) South of Melbourne, 2.4 km. S. jct. Rt. 9 & CR. 3 (36°1.53'N; 091°54.81'W)

Specimen identifications were furnished by the following specialists for each group as listed: T. Cohn, University of Michigan (Gryllacrididae); P. W. Kovarik, Columbus State Community College (Histeridae); P. E. Skelley, Florida State Collection of Arthropods (Scarabaeidae). Material from this study will be deposited in the collections of the following institutions: Arkansas State University, Florida State Collection of Arthropods, and the University of Michigan.

Results

Insects collected in Ozark pocket gopher burrows include cave crickets, anthomyiid flies, and histerid, rove and scarab beetles. Species of both rove beetles and anthomyiid flies remain undetermined. The list of identified species is listed in the following format: scientific name, abbreviated locality, date, number collected, and collecting method.

Coleoptera

Histeridae
Atholus minutus Ross
North of Guion, 9-12.IV.2005, (2), pitfall traps
South of Melbourne, 9-12.IV.2005, (1), pitfall traps
Atholus nubilus J. L. LeConte
South of Melbourne, 9-12.IV.2005, (6), pitfall traps
Geomysaprinus new species
South of Melbourne, 10-12.IV.2005, (4), pitfall traps
Onthophilus kirni Ross
Guion, 2-4.IV.2004, (2) pitfall traps
South of Melbourne, 27.I.2008, (93), nest/chambers excavation
South of Melbourne, 3.II.2008, (30), nest/chambers excavation
South of Melbourne, 23.III.2008, (11), nest/chambers excavation
South of Melbourne, 26.III.2008, (4), nest/chambers excavation
South of Melbourne, 28.III.2008, (2), nest/chambers excavation
Spilodiscus gloveri (Horn)
South of Melbourne, 10-12.IV.2005, (1), pitfall traps
South of Melbourne, 27.I.2008, (3), nest/chambers excavation
South of Melbourne, 3.II.2008, (9), nest/chambers excavation
South of Melbourne, 23.III.2008, (2), nest/chambers excavation
South of Melbourne, 28.III.2008, (3), nest/chambers excavation

Scarabaeidae
Cryptoscatomaseter haldemani (Horn)
Guion, 2-4.IV.2004, (2) pitfall traps
South of Melbourne, 20.XII.2007, (9), surface latrine mound
South of Melbourne, 6.I.2008, (1), pitfall traps
South of Melbourne, 27.I.2008, (22), nest/chambers excavation
South of Melbourne, 3.II.2008, (4), nest/chambers excavation
South of Melbourne, 23.II.2008, (1), nest/chambers excavation
South of Melbourne, 23.III.2008, (1), nest/chambers excavation
Cryptoscatomaseter oklahomensis (Brown)
South of Melbourne, 9-12.IV.2005, (16), pitfall traps
South of Melbourne, 19.XII.2007, (5),
South of Melbourne, 20.XII.2007, (12) surface latrine mound
South of Melbourne, 6.I.2008, (1), pitfall traps
South of Melbourne, 27.I.2008, (62), nest/chambers excavation
South of Melbourne, 3.II.2008, (8), nest/chambers excavation
South of Melbourne, 23.II.2008, (47), nest/chambers excavation

South of Melbourne, 23.III.2008, (59), nest/chambers excavation
South of Melbourne, 26.III.2008, (3), nest/chambers excavation
South of Melbourne, 28.III.2008, (22), nest/chambers excavation
Dellacasiellus kirni (Cartwright)
North of Guion, 9-12.IV.2005, (1), pitfall traps
South of Melbourne, 9-12.IV.2005, (4), pitfall traps
South of Melbourne, 12-22.IV.2005, (5), pitfall traps
Geomyphilus insolitus (Brown)
North of Guion, 9-12.IV.2005, (3), pitfall traps
North of Guion, 12-22.IV.2005, (4), pitfall traps
South of Melbourne, 10-12.IV.2005, (1), pitfall traps
South of Melbourne, 12-22.IV.2005, (1), pitfall traps
South of Melbourne, 20.XII.2007, (23), surface latrine mound
South of Melbourne, 27.I.2008, (203), nest/chambers excavation
South of Melbourne, 3.II.2008, (59), nest/chambers excavation
South of Melbourne, 23.II.2008, (13), nest/chambers excavation
South of Melbourne, 23.III.2008, (18), nest/chambers excavation
South of Melbourne, 28.III.2008, (72), nest/chambers excavation
Scabrostomus sepultus (Cartwright)
South of Melbourne, 12-22.IV.2005, (1), pitfall traps
South of Melbourne, 20.XII.2007, (15), surface latrine mound
South of Melbourne, 6.I.2008, (1), pitfall traps
South of Melbourne, 27.I.2008, (5), nest/chambers excavation
South of Melbourne, 3.II.2008, (14), nest/chambers excavation
South of Melbourne, 23.II.2008, (1), nest/chambers excavation
South of Melbourne, 23.III.2008, (1), nest/chambers excavation

Orthoptera

Gryllacrididae
Ceuthophilus fusiformis Scudder
Guion, 2-4.IV.2004, (3 ♂) pitfall traps
Ceuthophilus new species
Guion, 2-4.IV.2004, (several ♂) pitfall traps
[note: *Ceuthophilus* spp. were collected at additional localities in 2005 but have not yet been identified]

Discussion

The pitfall sampling in April 2004-2005 yielded five species of histerids, five species of scarabs, and two species of cave crickets. All of these species were new state records for Arkansas, and one of the crickets and one of the histerids are new to science. Prior sampling of inquilines in the burrow of *Geomys pinetus* (Rafinesque) by Skelley and Kovarik (2001) demonstrated that if at least three pitfalls were allowed to operate undisturbed in a given area during the period of peak insect activity, most of the niche-specific species could be collected. Although we had problems with flooding, a total of seven pitfall traps were successfully run in Izard County and we had every reason to believe that we had collected most of the insect species inhabiting the burrows of the Ozark pocket gopher. In 2007 and 2008 additional pitfall sampling and excavations of nest/associated chambers were carried out. Since most of the beetles inhabit the nest/fecal chambers, excavations are an extremely thorough means of sampling. The extra sampling produced no additional species of insects.

While the known distributions of most of the determined insects inhabiting the burrows of the Ozark pocket gopher should be regarded as preliminary, some general trends are apparent. All of the scarabs are essentially Great Plains species. Three species, including *C. haldemani*, *C. oklahomensis*, and *S. sepultus* are confined to the southern Great Plains while *D. kirni* and *G. insolitus* extend into the northern Great Plains, including prairie remnants in Illinois, Indiana, and Wisconsin (Kriska and Katovich 2006, Gordon and Skelley 2007). Otherwise, none of the scarabs occur east of the Mississippi River. Two of the histerid species, *O. kirni* and *A. minutus*, do occur east of the Mississippi River (Helava 1978, Ross 1940). *Atholus minutus* also occurs in the northern Great Plains whereas *O. kirni* does not occur north of southern Kansas (Kovarik unpubl.). With regard to the crickets, *Ceuthophilus fusiformis* inhabits the northern and southern Great Plains (Hubbell 1936) and occurs west of the range of the eastern pocket gopher (*Geomys* spp.) where it presumably associates with the western pocket gopher (*Thomomys* spp.). *Ceuthophilus fusiformis* ranges just east of the Mississippi River in Illinois but remains west of Mississippi in the southern part of its range. Conversely, the new *Ceuthophilus* is known to occur in western Florida and Alabama.

The discovery of the histerid *A. nubilus* in the burrows of the Ozark pocket gopher was surprising. This is the first time that this species of beetle has been collected from pocket gopher burrows. Enough specimens of this species were collected to make it

unlikely that its occurrence in the burrow was accidental. This species is obviously not restricted to pocket gopher burrows, as it occurs in Mississippi where pocket gophers are absent. *Atholus nubilus* is the same size class as the common and widespread burrow inhabiting histerids, *Geomysaprinus goffi* Ross and *G. rugosifrons* (Fall), which were notably absent from the burrows of the Ozark pocket gopher. It is tempting to postulate that a vacant niche has been filled by a species not normally associated with pocket gophers.

A survey of the Coleoptera inhabiting burrows of *Geomys breviceps* in Louisiana (Tishechkin and Cline 2008) demonstrated a significant overlap in the burrow fauna of Izard County and Louisiana. Missing from Louisiana were the scarab *C. oklahomensis* and the histerid *Geomysaprinus* new species. Missing from Izard County were the scarabs *Cryptoscatomaster acuminatus* (Cartwright) and the histerid *G. goffi*.

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Ionization Rate, Temperature, and Number Density for Breakdown Waves with a Large Current Behind the Shock Front

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Abstract

A three component, one-dimensional, constant velocity, steady-state fluid model is employed to describe the breakdown waves with a current behind the wave front propagating into a neutral gas subjected to an external electric field. Electron gas partial pressure is much larger than that of the other species and therefore is considered to provide the driving force for the wave. The system of equations includes the equations of conservation of mass, momentum, and energy coupled with Poisson's equation.

Inclusion of current behind the wave front in the system of fluid equations also alters the initial boundary conditions and ionization rate. We are considering an ionization rate which changes from accelerational ionization at the front of the wave to directed velocity ionization in the intermediate stages of the wave to thermal ionization at the end of the wave. Using the modified boundary conditions, the set of electron fluid dynamical equations have been integrated through the dynamical transition region of the wave. The effect of current behind the shock front on the wave profile for electric field, electron velocity, ionization rate, electron number density, and electron temperature will be presented.

Background

Breakdown waves are propagating processes converting ionless gas into neutral plasma. Lightning is the classic example of propagating breakdown waves. Depending on the direction of the electric field force on the electrons, breakdown waves are referred to as: proforce and antiforce waves. For proforce waves the electric field force on electrons is in the direction of wave propagation yet for antiforce waves it is in the opposite direction of wave propagation. The study of breakdown waves first began with Hauskbee in 1705 by studying luminous pulses in evacuated chambers. In 1893, Thompson discovered that breakdown waves travel with speeds as high as half the speed of light (Thompson 1893). Beams confirmed Thompson's results and he proposed that electron gas partial pressure provides the driving force for breakdown waves (Beams 1930). Finally, the fluid model was proposed independently by Paxton and Fowler (1962) and Haberstich (1964) to describe breakdown waves as fluid phenomena. To describe the waves, Shelton and Fowler (1968) referred to them as "Electron Fluid Dynamical" (EFD) waves since there is negligible mass motion and the phenomenon is solely caused by electron fluid action. They also derived equations for momentum and energy transfer operators along with the boundary conditions at the wave front. Fowler and Shelton (1974) then used an approximation method to solve the electron fluid dynamical equations for the sheath region of proforce waves. The EFD equations include the equations of the conservation of mass, momentum, and energy along with Poisson's equation. Major modifications to the equations, including the heat conduction term in the equation of conservation of energy and inclusion of electron gas temperature derivative at the shock front, were made by Fowler et al. (1984). Modifications calculating ionization rate were also made by Fowler (1983).

There are two main regions of breakdown waves: the sheath region and the quasi-neutral region. The sheath region is a thin dynamical region that follows the shock front. In this region, the electric field decreases to a minimal value and electrons slow down to rest due to collisions with heavy particles. The quasi-neutral region is a thicker area that follows the sheath region where the ionization of heavy particles continues, causing the electron gas to cool. When a substantial current is behind the shock front of a proforce wave, it is known as a proforce current-bearing wave. For breakdown waves with a current behind the shock front, the equations of conservation of mass, momentum, and energy remain unchanged. However, Poisson's equation must be modified. The initial boundary conditions for electric field and electron velocity remain unchanged, yet there is a necessary modification for the shock condition on electron temperature.

The modified set of electron fluid dynamical equations was integrated through the dynamical

transition region of the wave using the modified boundary conditions and the trial and error method. The current behind the shock front effects the electron fluid dynamical equations, boundary conditions, and therefore changes the wave profile. The results from the integrations satisfy the required conditions at the end of the sheath region. The wave profiles for electron velocity, electron temperature, electron number density, electric field, and the ionization rate were determined.

Analysis

To analyze breakdown waves propagating into a neutral medium, we utilized a set of one-dimensional, steady-state, electron fluid dynamical equations developed by Fowler et al. (1984). This set of EFD equations consists of the equations of conservation of mass, momentum, and energy coupled with Poisson's equation:

$$\frac{d(n\upsilon)}{dx} = \beta n \tag{1}$$

$$\frac{d}{dx}[mn\nu(\upsilon - V) + nkT_e] = -enE - KmnV(\upsilon - V) \tag{2}$$

$$\frac{d}{dx}[mn\upsilon(\upsilon - V)^2 + nkT_e(5\upsilon - 2V) + 2en\upsilon\phi + \varepsilon_0 VE^2 - \frac{5nk^2T_e}{mK}\frac{dT_e}{dx}] = -3(\frac{m}{M})nkKT_e - (\frac{m}{M})Kmn(\upsilon - V)^2 \tag{3}$$

$$\frac{dE}{dx} = \frac{e}{\varepsilon_0}n(\frac{\upsilon}{V} - 1) \tag{4}$$

where *n, v, Te, e,* and *m* respectively represent the electron number density, velocity, temperature, charge, and mass. Also, *M* represents neutral particle mass, *E* is electric field within the sheath region, E_0 is electric field at the wave front, *V* is wave velocity, *k* is the Boltzmann's constant, *K* is the elastic collision frequency, *x* is the position within the sheath, β is the ionization frequency, ϕ represents the ionization potential of the gas, and ε_0 is the permittivity constant.

We reduce the electron fluid dynamical equations to their non-dimensional form using the following dimensionless variables:

$$\eta = \frac{E}{E_o},\ \nu = (\frac{2e\varphi}{\varepsilon_o E_o^2})n,\ \psi = \frac{v}{V},\ \theta = \frac{T_e k}{2e\varphi},$$
$$\xi = \frac{eE_o x}{mV^2},\ \alpha = \frac{2e\varphi}{mV^2},\ \kappa = \frac{mV}{eE_o}K,\ \mu = \frac{\beta}{K},$$
$$\omega = \frac{2m}{M}$$

where η is electric field strength within the sheath, v is electron number density, ψ is electron velocity, θ is the electron gas temperature, μ is ionization rate, ξ is the position within the sheath region, and ω is the ratio of electron mass over neutral particle mass. α and κ are wave parameters.

These dimensionless variables are substituted into equations 1 through 4, yielding:

$$\frac{d(v\psi)}{d\xi} = \kappa\mu v \tag{5}$$

$$\frac{d}{d\xi}[v\psi(\psi - 1) + \alpha v\theta] = -v\eta - \kappa v(\psi - 1) \tag{6}$$

$$\frac{d}{d\xi}[v\psi(\psi - 1)^2 + \alpha v\theta(5\psi - 2) + \alpha v\psi + \alpha\eta^2 - \frac{5\alpha^2 v\theta}{\kappa}\frac{d\theta}{d\xi}] = -\omega\kappa v[3\alpha\theta + (\psi - 1)^2] \tag{7}$$

$$\frac{d\eta}{d\xi} = \frac{v}{\alpha}(\psi - 1) \tag{8}$$

To calculate ionization rate, μ, we utilize an equation introduced by Fowler (1983), which is a computation based on free trajectory theory and includes ionization from random as well as directed electron motions:

$$\mu = \mu_0 \int_A^\infty \sigma_i x^2 dx \int_B^\infty \frac{e^{-(x-u)^2} - e^{-(x+u)^2}}{u} due^{-2Cu} \tag{9}$$

where

$$A = \frac{1}{\sqrt{2\theta}},\ B = \frac{(1-\psi)}{\sqrt{2\alpha\theta}},\ C = k\sqrt{2\alpha\theta}\ .$$

We expand the equation of conservation of linear momentum (equation 6) and also the equation of conservation of mass (equation 5), then substitute from the expanded form of the conservation of mass into the expanded form of the equation of conservation of linear momentum to solve for the electron velocity derivative with respect to position, $\frac{d\psi}{d\xi}$. The singularity inherent in the set of EFD equations appears in the denominator of the resulting equation:

$$\frac{d\psi}{d\xi} = \frac{k(1+\mu)(1-\psi)\psi - \kappa\mu\alpha\theta - \eta\psi - \alpha\psi\theta'}{\psi^2 - \alpha\theta} \quad (10)$$

For proforce waves with a current behind the shock front, modifications must be made for the initial boundary conditions and Poisson's equation. The equation of conservation of current at the wave front is

$$eN_iV_i - env = I \quad (11)$$

where I represents the current, n is the number of electrons per unit volume, N_i is the number of ions per unit volume, and V_i is the ion velocity in the wave frame. Substituting from the equation of conservation of current into Poisson's equation results in:

$$\frac{dE}{dx} = \frac{e}{\varepsilon_0}\left(\frac{I}{eV_i} + \frac{nv}{V_i} - n\right). \quad (12)$$

Considering that the change in ion velocity is negligible and introducing the dimensionless variables along with $\iota = \frac{I}{\varepsilon_0 E_0 K}$ as dimensionless current in Poisson's equation (equation 12) reduces it to:

$$\frac{d\eta}{d\xi} = \frac{\nu}{\alpha}(\psi - 1) + \kappa\iota. \quad (13)$$

Integrating the all particle (electrons, ions, and neutral particles) equation of conservation of momentum, evaluating the constant of integration utilizing the variable values at the wave front, introducing all relevant dimensionless variables, and solving for electron temperature at the wave front, θ_1, results in the following equation for electron temperature at the shock front:

$$\theta_1 = \frac{\psi_1(1-\psi_1)}{\alpha} + \frac{\kappa}{\nu_1}\iota. \quad (14)$$

Results

The singularity inherent in the set of equations that appears in the denominator of equation 10 is utilized to integrate the set of equations through the sheath region. For given α and κ values, a set of ν_1 and ψ_1 values are selected to integrate the set of equations through the sheath region. While integrating the set of equations, the values of numerator and denominator in equation 10 are compared. If the denominator in equation 10 approaches zero, the electron velocity derivative with respect to position approaches infinity. This indicates the existence of a shock within the sheath, which is not allowed. Therefore, with gradual change in the value of ν_1, we pass through the singularity where the numerator and denominator values in equation 10 are almost equal and maintaining the values of numerator and denominator constant for ten integration steps. At the conclusion of integration of the equations through the sheath region, if the required conditions at the end of the sheath are not achieved, we change the value of ψ_1 by trial and error until the conditions are achieved at the end of the sheath ($\psi_2 \rightarrow 1$ and $\eta \rightarrow 0$).

In studying lightning attachment processes, Wang et al. (1999) obtained highly resolved optical images, electric field measurements, and channel-base current readings for dart leader/return-stroke lightning flashes triggered using the rocket-and-wire technique at Camp Blanding, Florida. They reported return-stroke peak currents of 21 kA and 12 kA. Directly measuring the time derivative of the electric field of triggered lightning strokes at distances of 10 m to 30 m, Uman et al. (2000) reported peak current values of 24 kA - 5.5 kA. A current value of 5000 A represents an ι value of approximately 0.1.

We have integrated the set of electron fluid dynamical equations through the sheath region for a zero current value and also current values of 0.1 and 0.2. A current behind the shock front changes the wave profile and will be further discussed.

Figure 1 depicts electric field, η, as a function of electron velocity, ψ, within the sheath region. An α value of 0.1 was selected which represents a wave speed of 9.37×10^6 m/s. To ensure successful integration through the sheath region, for current values of 0.1 and 0.2, the initial boundary values were ψ_1 = 0.2525, ν_1 = 0.240, κ = 0.823; ψ_1 = 0.260, ν_1 = 0.280, and κ = 0.849, respectively. The solutions met the expected physical conditions at the end of the sheath where $\psi_2 \rightarrow 1$ and $\eta_2 \rightarrow 0$.

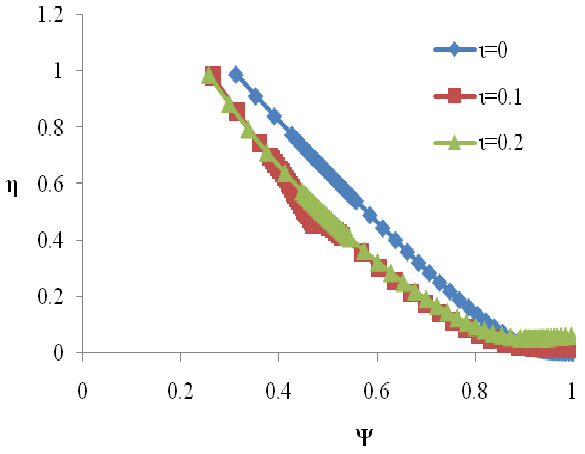

Figure 1. Electric field, η, as a function of electron velocity, Ψ, inside the sheath.

Figure 2 contrasts electron temperature, θ, as a function of position, ξ, within the sheath region. As expected, the temperature of the electron gas decreases as the position within the sheath increases. For ι = 0.2, the electron gas temperature reduces to θ_f = 0.316 at the end of the sheath. This represents a gas temperature of 1.83×10^5 K. A ξ value of 1.5 at the end of the sheath represents a sheath thickness of 3.3×10^{-5} m.

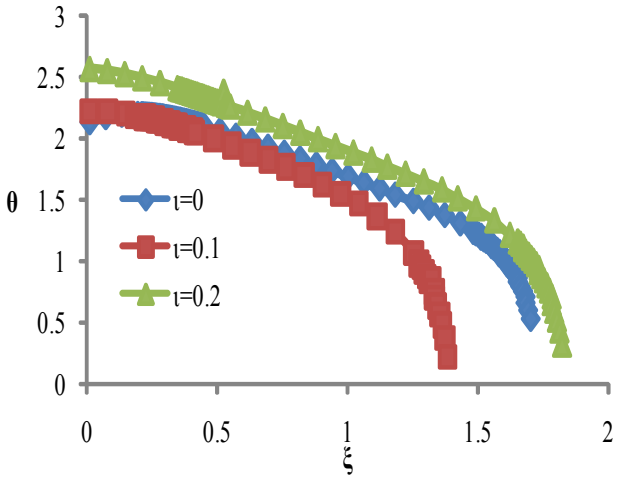

Figure 2. Electron gas temperature, θ, as a function of position, ξ, inside the sheath.

Figure 3 is a graph of electron number density, ν, as a function of position, ξ, within the sheath region. For ι = 0.1, there is a visible jump or kink in the electron number density values around the position where ξ = 0.4. This results from approximation utilized in order to pass through the singularity. For ι = 0.1, the electron number density reduces to 0.1641 at the end of the sheath. This represents an electron number density of 1.82×10^{17}electrons/m^3.

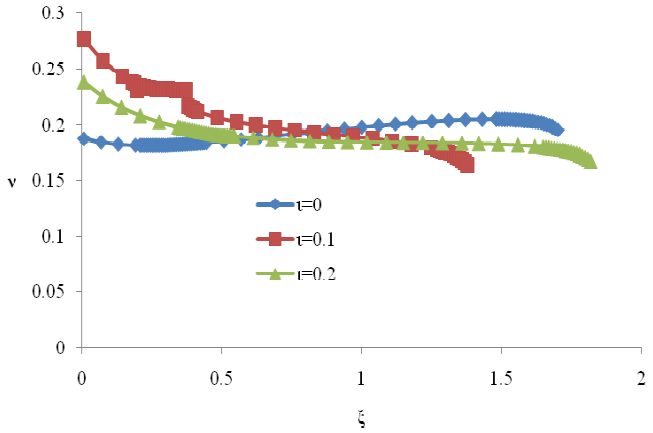

Figure 3. Electron number density, ν, as a function of position, ξ , inside the sheath.

Figure 4 depicts ionization rate, μ, as a function of position, ξ, within the sheath region. Shelton (1968) assumed that the ionization rate was constant throughout the sheath region. The graph shows that for all different values of current the ionization rate remains constant at the beginning of the sheath. However, it changes considerably at the end of the sheath.

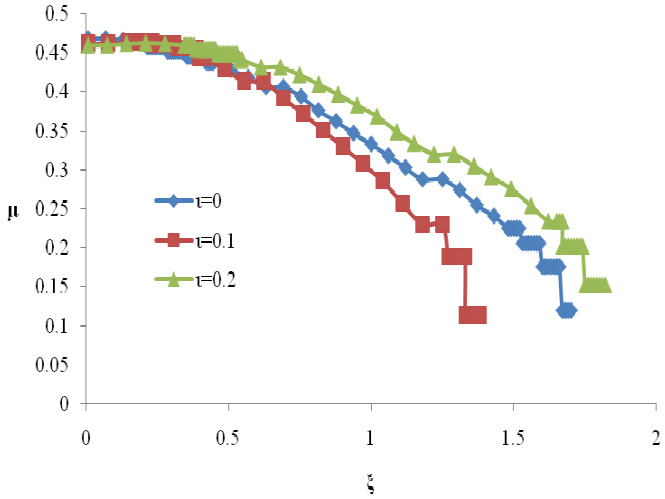

Figure 4. Ionization rate, μ, as a function of position, ξ, inside the sheath.

Conclusions

For the current values reported by the Uman et al. (2000) and Wang et al. (1999), we were able to integrate the electron fluid dynamical equations through the sheath region. Our solutions met the expected physical conditions at the end of the sheath. Calculation of ionization rate using an equation based on the free trajectory theory allows for a successful integration of the electron fluid dynamical equations for breakdown waves with a large current behind the shock front. Our results on ion number density compare well with those reported by Gogolides and Sawin (1992) and Degeling and Boswell (1997). Our ionization rate values compare well with observations made by Brok et al. (2003). This is another confirmation on the application of the fluid model to breakdown waves with a large current behind the shock front.

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The Arkansas Endemic Biota: An Update with Additions and Deletions

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Abstract

It has been over a decade since the publication of Robison and Allen (1995) that provided the definitive list of endemic flora and fauna of Arkansas. The present study brings up-to-date the endemic biota of the state. Since 1995, several new species have been described and new discoveries have been made, adding species to the state biota. Other species are deleted and new distributional information on other state endemics is presented. Specifically, 3 new plant species are added to the state list while 4 plant species are deleted. Sixteen new animal species/subspecies are added to the state list while numerous species are deleted. These changes bring to 110 (10 species of plants and 100 species/subspecies of animals) the total number of Arkansas state endemic plants and animals presently known, which represents a decrease by 7 species from the 117 species reported in 1995.

Introduction

Robison and Allen (1995) published the definitive list of endemic plants and animals of Arkansas. Since it has been over a decade since the appearance of Robison and Allen (1995), it seems entirely appropriate to bring up-to-date the endemic biota of the state. New species have been described and new discoveries have been made, adding species to the state biota. Additional discoveries require deletions of several species previously believed to be state endemics. In this publication, we bring up-to-date the state endemic biota, including new species additions, species requiring deletion, and adding distributional information on other state endemics.

PLANTS

Additions to State Endemic Flora

Order Gentianales
Family Gentianaceae

Sabatia arkansana Pringle and Witsell 2005 – Pelton's Rose-gentian

Pringle and Witsell (2005) described this new species of rose-gentian from Saline County glades. It occurs on shale glades (on Womble Shale of Middle Ordovician age) in the eastern Ouachita Mountains and on nepheline syenite glades (igneous intrusions of Late Cretaceous age) in the Upper West Gulf Coastal Plain of Saline County.

Order Asterales
Family Asteraceae

Liatris compacta (Torr. & Gray) Rydb. 1931 – Blazing Star

This blazing star is endemic to a portion of the Ouachita Mountains in Arkansas and is thus added to the state list of endemics (http://efloras.org/florataxon.aspx?flora_id=1&taxon_id=250067095) [Flora North America, Vol. 21, p. 517] (http://www.naturalheritage.com/program/rare-species/federally-listed/plant-profiles/blazing_star.asp).

Order Brassicales
Family Brassicaceae

Streptanthus maculatus Hook ssp. *obtusifolius* (Hook.) Rollins 1959 – Clasping Twistflower

This twistflower is added to the Arkansas list of endemic plants. It is known from Faulkner, Garland, Hot Spring, Howard, Montgomery, Polk, Pulaski, and Saline counties. *Streptanthus obtusifolius* was formerly (Kartesz 1994) considered within the range of variability for *S. maculatus* but Kartesz and Meacham (1999) subsequently recognized it as a subspecies. Recent authors have followed the Kartesz lead.

Deletions from State Endemic Flora

Order Jungermanniales
Family Lejeuneaceae

Plagiochila japonica Sande Lac. ex Miquel subspecies *ciliigera* 1959 – Liverwort

The liverwort *Plagiochila japonica* and the subspecies *P. japonica* subsp. *ciliigera* are not currently considered to be separate from *P. sciophila* Nees ex Lindeb. *P. sciophila* is widespread in Asia and in North America is known from the Blue Ridge in the

Southern Appalachians, the Cumberland Plateau, and a single location in the Ozark Mountains. Heinrichs et al. (2004) summarized the results of their morphological, molecular, and chemical work and presented an updated section and species list for *Plagiochila*. They noted that *Plagiochila* is notorious for variation in gametophytic characters, especially leaf shape and dentation.

Order Caryophyllales
Family Caryophyllaceae
Arenaria muriculata Maguire 1951 – Sandwort

Arenaria muriculata has been lumped (along with several other taxa) as a synonym under *A. muscorum* (Fassett) Shinners. This group is now treated in the genus *Minuartia* (see Flora of North America website at http://hua.huh.harvard.edu/FNA/; Arkansas Vascular Flora Committee 2006). Before the merger, *Arenaria muriculata* had been found in Texas, so regardless of how it is treated, it is no longer endemic only to Arkansas.

Order Cyperales
Family Cyperaceae
Carex opaca (F. J. Hermann) P. E. Rothrock & Reznicek 1972 – Sedge

This sedge has been elevated to full species rank as *Carex opaca* (F. J. Herm.) by Rothrock and Reznicek (2001). It is now known from several other states and should be omitted from the list of state endemics. A distribution map for this species can be seen at the following site: (http://www.efloras.org/object_page.aspx?object_id=9479&flora_id=1)

Order Brassicales
Family Brassicaceae
Cardamine angustata var. *ouachitana* E. B. Smith 1982 – Toothwort

The recently published Checklist of the Vascular Plants of Arkansas (Arkansas Vascular Flora Committee 2006) merges this variety into synonymy with the species. Also, the online database known as ITIS (Integrated Taxonomic Information System; http://www.itis.gov/) does not accept this variety but considers it within the range of variation for the species. Similarly, the online database known as MorphoBank (http://morphobank.geongrid.org/) does not recognize this taxon. For these reasons, *Cardamine angustata* var. *ouachitana* E.B. Smith is deleted from the list of state endemic plants.

New Distributional Information
Order Ranunculales
Family Ranunculaceae
Delphinium newtonianum D. M. Moore 1939 – Moore's Delphinium

This state endemic has now been documented from 8 counties including Johnson, Montgomery, Newton, Pike, Polk, Pope, Searcy, and Van Buren (ANHC database; http://www.naturalheritage.com/program/inventory.asp).

Order Rosales
Family Rosaceae
Mespilus canescens Phipps 1990 – Stern's Medlar

Phipps (1990) described this species from Slovak in Prairie County as the only American species of its genus. Prior to the discovery of Stern's Medlar, the genus *Mespilus* was comprised of a single species native to western Eurasia but cultivated far beyond that area for its edible fruit and known as medlar. The closely related genus *Crataegus*, on the other hand, was known to include 140-200 or more species of hawthorns throughout the northern hemisphere. A recent paper by Lo et al. (2007), however, provides strong documentation to support a hybrid origin for Stern's Medlar. On the basis of comparative molecular studies, the authors (Lo et al. 2007) propose a hybrid origin from our native species *Crataegus brachyacantha* and the Eurasian *Mespilus germanica*. They further propose that the species should be known as *Crataegus X canescens* (J. B. Phipps) T. A. Dickinson and E. Y. Y. Lo.

A hybrid origin for Stern's Medlar presupposes that a cultivated specimen of medlar came into contact with a native plant of *Crataegus brachyacantha*, the blueberry hawthorn. The blueberry hawthorn is known from several Arkansas counties in the Delta and Coastal Plain regions, but has not been reported from Prairie County, the only known locality for Stern's Medlar. The Slovak area was home to Czechs and other settlers having an Eastern European origin. Although seldom seen today, medlar fruits were much prized in the past and much planted throughout Europe. Cultivation of medlar by one or more of these early settlers is not unexpected.

Order Fagales
Family Fagaceae
Quercus shumardi Buckl. var. *acerifolia* E. J. Palmer 1926 – Maple-Leaved Oak

A recently published volume of *Flora North America* [Volume 3] elevated this taxon to the rank of full species, i.e. *Quercus acerifolia* (E. J. Palmer) N. A.

Stoynoff & W. J. Hess based upon Stoynoff and Hess (1990) (http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=233501004). Later, Hess and Stoynoff (1998) completed a morphological comparison of 4 members of the *Quercus shumardii* complex.

The maple-leaved oak was believed to be endemic to Magazine Mountain, Logan County, in the Arkansas River Valley province (Robison and Allen 1988) until 1991. Johnson (1992) extended the known distribution to Pryor Mountain, Montgomery County, and Sugarloaf Mountain, Sebastian County. In 1993 an additional population was discovered on Porter Mountain, Polk County, bringing the total known populations to 4 (Rouw and Johnson 1994).

Order Boraginales
Family Hydrophyllaceae
Hydrophyllum brownei Kral and Bates 1991– Browne's Waterleaf

Travis Marsico evaluated this species in his Master's Thesis (Marsico 2004) at the University of Arkansas-Fayetteville and subsequently published his findings (Marsico 2003, 2006). Browne's Waterleaf was originally known from only one site in Saline County; however, John Pelton and Theo Witsell (pers. comm.) have found several additional stations for this species in Saline County on rich wooded terraces of the Alum Fork and North Fork of the Saline River. In addition to Saline County, it is now known from 7 other Arkansas counties, including Garland, Howard, Montgomery, Pike, Polk, Sevier, and Yell (Marsico 2006).

Order Rubiales
Family Rubiaceae
Galium arkansanum var. *pubiflorum* E.B. Smith 1979 – Arkansas Bedstraw

The Checklist of the Vascular Plants of Arkansas recognizes this variety, although ITIS does not accept this variety, but considers it within the range of variation for the species. We continue to recognize this variety as a separate variety endemic to Arkansas.

Order Asterales
Family Asteraceae
Polymnia cossatotensis A.B. Pittman and V. Bates 1989– Cossatot Leafcup

This plant is an endemic of the Interior Highlands region of Arkansas. It was discovered in 1988 and is only known from 4 sites, Gap and Pryor mountains in Montgomery County and Blaylock and Brush Heap mountains in Polk County (Hardcastle et al. 2007). Because of its extreme rarity, *P. cossatotensis* is listed as G1 and is considered critically imperiled (NatureServe 2008).

ANIMALS

Additions to State Endemic Fauna
Order Amphipoda (scuds, sideswimmers)
Family Crangonyctidae
Crangonyx aka Zhang and Holsinger 2003

Described by Zhang and Holsinger (2003) from an unmarked stream in Pope County, ca. 0.5 mi (0.8 km) south of Hector on St. Hwy. 27 (USNM 230406 – Holotype. R. Fox. 28 Dec 1970).

Bacturus speleopolis Holsinger, Sawicki, and Graening 2006

Holsinger et al. (2006) described *Bacturus speleopolis*, a large stygobitic amphipod crustacean in the family Crangonychidae from specimens collected in an underground lake in Cave City, Sharp County. Specimens from Marble Falls Cave in Marion County may also be this species.

Diplopoda (millipeds)
Order Callipodida
Family Abacionidae
Abacion wilhelminae Shelley, McAllister, and Hollis 2003

It had been over 60 years since the fourth species of *Abacion* had been described when *A. wilhelminae* was discovered, an Arkansas endemic in Polk County. The type locality is in Polk County at the Pioneer Cemetery Historical Site, along AR Hwy 88 on Rich Mountain, approximately 1.5 mi (2.4 km) W Queen Wilhelmina State Park (Shelley et al. 2003). The species is known only from the type locality and 2 other sites at about 2,900 ft (884 m) elevation on Rich Mountain in Polk County. Two other species of *Abacion*, including *A. tesselatum* Rafineque and *A. texense* (Loomis) have also been reported from Rich Mountain (Shelley 1984). It is believed that *A. wilhelminae* is endemic to the western periphery of the Ouachita Physiographic Province, perhaps including LeFlore County, Oklahoma (Shelley et al. 2003). However, intensive collecting by one of us (CM) along the western portion of that range has yet to yield a specimen.

Order Chordeumatida
Family Trichopetalidae
Causeyella causeyae Shear 2003

This species was collected from several caves in the Ozarks of Arkansas and it appears to occur on both sides of the White River (Shear 2003). The holotype is unpigmented and eyeless and was collected in

Independence County at Foushee Cave, 6 mi (9.7 km) west of Locust Grove. The overall geographic distribution includes Independence, Izard, and Stone counties.

Causeyella youngsteadtorum Shear 2003

In their survey of north Arkansas caves, Youngsteadt and Youngsteadt (1978) recorded this species from Potato Cave, Searcy County. Shear (2003) notes that except for one record, *C. youngsteadtorum* occurs south of the White River, but north of the Buffalo River. The type locality is in Boone County at Brewer Cave. The overall distribution includes Boone, Newton, and Searcy counties.

Order Odonata (dragonflies)
Family Cordulegastridae
Cordulegaster talaria Tennessen 2004 - Ouachita Spiketail

This new dragonfly was described from a first-order tributary of the Caddo River at Caddo Gap in Montgomery County (Tennessen 2004). It was also reported from a site in Garland County and is considered endemic to the Ouachita Mountains of western Arkansas. Habitat of this new odonate is densely-shaded small seeps.

Order Rodentia
Family Geomyidae
Geomys bursarius ozarkensis Elrod, Zimmerman, Sudman, and Heidt 2000 – Ozark Mountain Pocket Gopher

Based on nucleotide sequence analysis of the cytochrome-*b* gene of mtDNA and analyses of cranial morphology, Elrod et al. (2000) described a new subspecies of pocket gopher from 3 mi (4.8 km) S of Melbourne in Izard County. It is currently known from extreme southern Izard County and possibly northeastern Stone County. Habitat includes sandy, deep soils of the floodplain of the White River.

Crustaceans - New Records or Changes in Nomenclature
Order Isopoda
Family Asellidae
Lirceus bicuspidatus Hubricht and Mackin 1949

This isopod was previous known from 8 Arkansas counties, including Conway, Jackson, Logan, Newton, Pope, Pulaski, Searcy, and Yell (Robison and Allen 1995). Graening et al. (2007) added Independence, Johnson, Saline, and Stone to the list of counties inhabited by *L. bicuspidatus*. The species is endemic to 12 counties of the state.

Millipeds - New Records or Changes in Nomenclature
Diplopoda
Order Polydesmida
Family Xystodesmidae
Boraria profuga (Causey) Hoffman and Shear 1969
syn. *Cibularia profuga* (Causey) 1955

There are 3 species in the genus (see Hoffman 1999). This xystodesmid is probably endemic to the Ouachita uplift of the state.

Nannaria davidcauseyi (Causey) 1950

The species was originally described in the genus *Mimuloria* (Chamberlin 1928). The holotype is from near Jasper, Newton County.

Nannaria depalmai (Causey) 1950

The species was originally described in the genus *Castanaria* (Causey 1950) and later transferred to *Mimuloria*. Most recently it has been placed in the genus *Nannaria* (Chamberlin 1918). The holotype is from 2 mi (3.2 km) S Lake Leatherwood, Carroll County.

Family Eurymerodesmidae
Eurymerodesmus compressus Causey 1952

Shelley (1990) designated a male neotype from 6 mi (9.7 km) west of El Dorado, Union County.

Eurymerodesmus goodi Causey 1952

The type locality is in Polk County; Shelley (1990) added Montgomery County to the range of this milliped.

Eurymerodesmus newtonus Chamberlin 1942
syn. *Eurymerodesmus bentonus* Causey 1950

Shelley (1990) synonymized *E. bentonus* with *E. newtonus*. The type locality remains the same and the range now includes Benton, Newton, and Washington counties.

Eurymerodesmus polkensis (Causey) Shelley 1990
syn. *Paresmus polkensis* Causey 1952

Shelley (1990) proposed the new combination above for *P. polkensis*. The species is now known from Montgomery, Polk (type locality), and Scott counties (Shelley 1990).

Eurymerodesmus pulaski (Causey) Shelley 1990
syn. *Leptodesmus hispidipes* Bollman 1888; *Paresmus pulaski* Causey 1950

Shelley (1990) proposed the new combination above for *P. pulaski*. The species distribution was restricted to Pulaski County (Shelley 1990). Robison

and Allen (1995, fig. 7.35) incorrectly added Grant County to the distribution. However, one of us (CTM) collected a male and 2 females from Shannon Hills, Saline County, on 26 December 2006, now deposited in the North Carolina State Museum of Natural Sciences (McAllister et al. 2008).

Order Julida
Family Parajulidae
Okliulus beveli Causey 1953

The genus includes 3 species, *O. carpenteri* Causey from Oklahoma, *O. foliatus* Loomis from Louisiana, and *O. beveli* Causey, known only from Junction City, Union County, Arkansas (Hoffman 1999). The latter site is situated on the Arkansas/Louisiana line, and finding specimens south of that line would remove this species from the Arkansas list of endemics.

Order Polyzoniida
Family Polyzoniidae
Petaserpes bikermani (Causey) Shelley 1998
syn. *Polyzonium bikermani* Causey 1951

A holotype was apparently not received at the Academy of Natural Sciences of Philadelphia (ANSP); Shelley (1998) selected a lectotype from paratype series at the FSCA. Shelley (1998) placed *Polyzonium* in the genus *Petaserpes*.

Order Chordeumatida
Family Cleidogonidae
Cleidogona arkansana Causey 1954

The holotype is possibly lost; *C. arkansana* may be a synonym of *C. unita* (see Shear 1972). This milliped is restricted in range to the type locality in Dallas County.

Tiganogona (=*Ozarkogona*) *glebosa* (Causey 1951) Shear 1972

The type specimen, formerly deposited in the ANSP, was lost in postal transit (Shear 1972; Hoffman 1999). Known only from 2 localities in Washington County (Shear 1972).

Tiganogona (= *Ozarkogona*) *ladymani* (Causey 1952) Shear 1972

The holotype is not at the American Museum of Natural History and its current location is unknown (Hoffman 1999). It is one of the few millipedes restricted to extreme northeastern Arkansas in Clay County.

Tiganogona moesta (Causey 1951)

The type specimen, formerly deposited in the ANSP, was lost in postal transit (Shear 1972). Known only from 2 localities in the state, Carroll and Washington counties.

Tiganogona (= *Ofcookgonia*) *steuartae* (Causey 1951) Shear 1972

The holotype, formerly deposited in the ANSP, was lost in postal transit (Hoffman 1999). Known only from Sebastian County.

Family Trichopetalidae
Trigenotyla parca (Causey 1951) Shear 1972

The genus currently includes 4 species, *T. parca* in northwestern Arkansas (Carroll Madison, Newton, and Washington counties) and 3 other species in northeastern, south-central, and east-central Oklahoma (McAllister and Shelley 2003; Shear 2003). The former is typically found in caves and the type locality is at Blue Spring, Carroll County (Shear 2003). Interestingly, this locality is just inside the Arkansas border and less than 0.16 mi (0.25 km) from the Stone County, Missouri, line. We concur with Shear (2003) who suggested *T. parca* will probably be found in Oklahoma and Missouri, which would remove it as an Arkansas endemic.

Insects - New Records or Changes in Nomenclature
Class Insecta (insects)
Order Diplura (diplurans)
Family Japygidae
Occasjapyx carltoni Allen 1988

McAllister and Carlton (2005) added a second record from a single specimen collected by CTM in Independence County, 6.1 mi (9.8 km) north of Pleasant Plains off US167 at Blevins Cave along Powers Creek. The specimen was collected within the twilight zone of the cave and is deposited in the invertebrate collection of the Louisiana State Arthropod Museum, Baton Rouge. This dipluran was originally described by Allen (1998) who reported it from a tributary of the Buffalo River in Newton County.

Order Microcoryphia (jumping bristletails)
Family Machilidae
Pedetontus gershneri Allen 1995

Allen (1995) described *P. gershneri* from Mossback Ridge on Magazine Mountain near Paris, Logan County. This species is found on the moist forest floor or among deciduous leaves or sometimes among coniferous pine needles mixed with deciduous leaves.

Order Collembola (springtails)
Family Entomobryidae
Pseudosinella dubia Christiansen 1960

Christiansen (1960) described this species from specimens collected in several rock crevices in the Devil's Den area of southwestern Washington County. Nothing is known about its life history.

Order Hemiptera (true bugs)
Family Miridae
Lopidea arkansae Knight 1965

This plant bug was described by Knight (1965) based on specimens from Garland County on 21 May 1952. It is allied to *L. davisi* Knight, but differs in the deep red color, also with short appressed, simple yellowish pubescence; male claspers distinctive of the species (Knight 1965, Fig. 8). Holotype male was collected 21 May 1952 in Garland County, "on hardy *Phlox*."

Order Coleoptera (beetles)
Family Staphylinidae
Pseudactium magazinensis Carlton and Chandler 1994 (a short winged mold beetle)

Carlton and Chandler (1994) described this beetle based on a small number of specimens collected from forest litter samples from Mt. Magazine, Logan County. The species can be identified based on male secondary sexual characters and genitalic details.

Pseudactium ursum Carlton 1995 (a short winged mold beetle)

Carlton (1995) described this second endemic *Pseudactium* species based on a small number of specimens collected in flight intercept traps and forest litter samples from the vicinity of Erby, Buffalo National River, Newton County. As with the previous species, identification is based on male secondary sexual and aeadeagal characters.

Family Carabidae
Anillinus magazinensis Sokolov and Carlton 2004 (a ground beetle)

Sokolov and Carlton (in Sokolov et al. 2004) described *A. magazinensis* based on specimens from Mount Magazine, Logan County.

Anillinus robisoni Sokolov and Carlton 2004 (a ground beetle)

Sokolov and Carlton (in Sokolov et al. 2004) described *A. robisoni* from 5 mi (8 km) SW of Big Fork, Polk County. The distribution of this endemic is the southern parts of the Ouachita National Forest in the vicinity of Shady Lake and Bard Springs Recreation Area near the boundary of Polk and Montgomery counties. Habitat of this beetle is deep forest litter in hardwood and pine/hardwood forests.

Anillinus tishechkini Sokolov and Carlton 2004 (a ground beetle)

Sokolov and Carlton (in Sokolov et al. 2004) described *A. tishechkini* from a single locality on Winona Forest Drive, ca. 10 mi (16.1 km) west of Lake Sylvia, Perry County, Arkansas. Habitat is litter in rocky upland pine/hardwood forest along a ridge top having extensive sandstone outcrops and small bluffs.

Anillinus is a large and growing genus of microcarabids with localized distributions across much of southeastern US, with a hotspot of species diversity in the southern Appalachian Mountains. Two additional species were described by Sokolov and Carlton (Sokolov et al. 2004) from nearby Latimer County, Oklahoma. A new species was recently discovered in southwestern Missouri and a suspected new species is known from a single female specimen collected near Fayetteville (Washington County) by Richard Leschen (pers. comm.). Arkansas undoubtedly harbors additional new species of *Anillinus.*

Family Dytiscidae
Heterosternuta phoebeae Wolfe and Harp 2003 (a predaceous diving beetle)

Wolfe and Harp (2003) described *H. phobeae* from specimens collected at Bear Creek at US65, Searcy County, on 30 May 1988 by G. L. Harp. This endemic is known from only second, third, and fourth order tributaries to the Buffalo River in the Ozark Mountains of north-central Arkansas. It was also collected from Newton County: Beech Creek at St. Hwy. 74, 0.8 mi. (1.3 km) south of Boxley, 1 July 1992; Little Buffalo River 4 mi (6.4 km) upstream from Parthenon on 30 June 1992; and Smith Creek at St. Hwy. 21 ca. 2 mi (3.2 km) south of Boxley on 1 July 1992. It is known from 4 additional localities in Searcy County.

Deletions from State Endemic Fauna

Order Decapoda
Family Cambaridae (crayfishes)
Procambarus ferrugineus Hobbs and Robison 1988

Procambarus ferrugineus is no longer considered a species but rather has been synonymized with *P. liberorum* (Crandall et al. 2008).

Procambarus liberorum Fitzpatrick 1978 – Osage Burrowing Crayfish

This crayfish was originally described by Fitzpatrick (1978) and later additional distributional

information was supplied by Hobbs and Robison (1988). This species should be deleted from the Arkansas list of endemics as it was recently found in Oklahoma by Robison and McAllister (2007).

Class Diplopoda (millipeds)
Order Spirostreptida
Family Cambalidae
Cambala arkansana Chamberlin 1942

Originally thought to be endemic to Randolph County (Chamberlin 1942), this milliped has been synonymized by Shelley (1979) with *C. minor* Bollman. The species has a vast range extending from extreme western Virginia to eastern Oklahoma, south through Kentucky and Tennessee to Louisiana (Shelley 1979).

Order Chordeumatida
Family Branneriidae
Branneria bonoculus Shear 2003

Originally reported only from an unknown site in Nevada County, Arkansas (Shear 2003b), this milliped was recently reported from Marion County, Texas, by McAllister et al. (2009). Further sampling may reveal a more extensive range.

Order Polydesmida
Family Sphaeriodesmidae
Desmonus pudicus (Bollman 1888) Causey 1958
syn. *Sphaeriodesmus pudicus* Bollman 1888

Originally thought to be endemic to the state in Clark and Pulaski counties (Causey 1958) but now reported from numerous sites in Louisiana, Missouri, Oklahoma, Texas, and Nuevo León, Mexico (Shelley 2000).

Family Xystodesmidae
Pleuroloma flavipes Rafinesque 1820
syn. *Zinaria miribilia* Causey 1951

The species was synonymized by Shelley (1980) as it is now considered an aggressive and successful taxon within and out of the state.

Family Euryuridae
Auturus evides (Bollman 1887)
syn. *Auturus florus* Causey 1950

Causey (1950) originally reported this milliped from Newton County. However, it is widespread in the central United States, from Oklahoma to Arkansas, and north to southeastern Minnesota (Shelley 1982).

Eurymerodesmus angularis Causey 1951

Originally thought to be endemic to Prairie County, Shelley (1990) added additional records for Arkansas, as well as new records from Louisiana, Mississippi and Missouri. More recently, McAllister et al. (2004) and McAllister and Shelley (2008) added 3 records from Texas and 1 from Louisiana, respectively.

Family Eurymerodesmidae
Eurymerodesmus dubius Chamberlin 1943

The type locality is in Pike County (Chamberlin 1943). Other sites in the state include Bradley, Clark, Garland, Hot Spring, Nevada, Ouachita, and Saline counties, with a disjunct record in Louisiana (Shelley 1990). Recently, McAllister et al. (2002b) added a record for Hempstead County and McAllister et al. (2002a) reported the species from Oklahoma for the first time.

Eurymerodesmus newtonus Chamberlin 1942

See account herein for *E. bentonus*.

Eurymerodesmus oliphantus Chamberlin 1942

The range was formerly thought to be restricted to Jackson County (Chamberlin 1942); however, Shelley (1990) reports records for Missouri and southern Illinois.

Eurymerodesmus schmidti Chamberlin 1943

Originally reported to be restricted to Polk County, this species has been synonymized with *E. birdi birdi* (Shelley 1990). The latter has an extensive distribution that includes several counties in the state as well as Kansas, Louisiana, Mississippi, Missouri, and Texas (Shelley 1990). McAllister et al. (2002a) reported *E. b. birdi* from Lafayette County and LeFlore County, Oklahoma, and McAllister et al. (2003) also reported specimens from Madison and Yell counties. More recently, McAllister and Shelley (2008) provided new records for *E. b. birdi* from Scott County, Cherokee County, Kansas, and Cass and Harrison counties, Texas.

Order Pseudoscorpiones
Family Chernetidae
Pseudoscorpions
Pseudozaona (=*Hesperochernes*) *occidentalis* (Hoff and Bosterli 1956)

This pseudoscorpion was originally described from Fincher Cave, Washington County (Hoff and Bosterli 1956). Muchmore (1974) extensively revised the pseudoscorpion genus *Herperochernes* and placed *Pseudozaona occidentalis* within it. Because *H. occidentalis* (Hoff and Bosterli) has now been documented from Missouri, Ohio, Oklahoma, and Texas, this pseudoscorpion is herein deleted from the list of Arkansas endemic species.

New Distributional Information

Order Decapoda (shrimps and crayfishes)

Family Cambaridae

Bouchardina robisoni Hobbs 1977 – Bayou Bodcau Crayfish

Bouchardina robisoni was described by Hobbs (1977) from specimens collected in Lafayette County. Robison (2006) reviewed the status and distribution of this endemic crayfish and added records from Columbia, Hempstead, Howard, and Nevada counties to its known distributional range. On the basis of Robison's report, Taylor et al. (2007) gave the crayfish a conservation status of threatened.

Cambaris causeyi Reimer 1966– Boston Mountains Crayfish

Discovered by H. H. Hobbs, Jr. in 1941 in Pope County and later described by Reimer (1966), this crayfish was known until 1992 from only 6 localities in Pope and Stone counties. Robison and Leeds (1996) found this species in 40 different localities in 5 new counties including Madison, Johnson, Franklin, Newton, and Searcy counties across northern Arkansas in the Ozark Mountains.

Fallicambarus gilpini Hobbs and Robison 1988 – Jefferson County Crayfish

Robison and Wagner (2005) reviewed the status of *F. gilpini* and discovered that this crayfish was not confined to the 3 localities reported by Hobbs and Robison (1988). The distribution now includes 8 localities in 2 Arkansas counties, Jefferson and Cleveland (see Robison and Wagner 2005).

Fallicambarus harpi Hobbs and Robison 1985 – Ouachita Burrowing Crayfish

Robison and Crump (2004) reviewed the status and distribution for this state endemic and found it to be a much more widely distributed crayfish than previously believed. They reported 12 new populations of this crayfish in Montgomery, Hot Spring, Garland, and Pike counties. Previously, it had been known from a single location in Pike County (Hobbs and Robison 1985).

Fallicambarus petilicarpus Hobbs and Robison 1989 – Slenderwrist Burrowing Crayfish

Hobbs and Robison (1989) described *Fallicambarus petilicarpus* from a single locality in western Union County. Later, Robison (2001) reviewed the status and distribution of this state endemic and found it to be rare and never abundant locally. He added Columbia County to the known distribution of this crayfish.

Summary

Since the publication of Robison and Allen (1995), significant changes in our knowledge of the endemic biota of the state have occurred. Included among these changes are the addition of 3 new plant species (*Sabatia arkansae*, *Streptanthus maculatus obtusifolius*, and *Liatris compacta*) to the state list and the deletion of 4 plant species (*Plagiochila japonica ciliigera*, *Arenaria muriculata*, *Carex opaca, and Cardamine augustata ouachitana*). In addition, we have summarized the new distributional information on various plant endemics that is now available.

Sixteen new animal species/subspecies have been added to the state endemic list, including 3 species of millipeds (*Abacion wilhelminae, Causeyella causeyae, Causeyella youngsteadtorum*), 2 amphipods (*Crangonyx aka*, *Bacturus speolopsis*), 1 bristletail (*Pedetontus gershneri*), 1 springtail (*Pseudosinella dubia*), 1 dragonfly (*Cordulegaster talaria*), 1 plant bug (*Lopidea arkansae*), 6 beetles (*Pseudactium magazinensis*, *P. ursum*, *Anillinus magazinensis*, *A. robisoni*, *A. tishechkini*, and *Heterosternuta phoebeae*), and 1 gopher (*Geomys bursarius ozarkensis*). Deletions from the 1995 original list include 2 crayfishes (*Procambarus ferrugenius* and *P. liberorum*) and numerous millipeds.

With these changes considered, we document a total of 110 taxa (species and subspecies) of plants and animals as endemic to the state of Arkansas, including 10 species of plants and 100 species of animals (Table 1). The animals are dominated by 91 invertebrates, which include 2 annelid worms, 8 snails, 3 mussels, 21 crustaceans, (4 amphipods, 4 isopods, and 13 crayfishes), 20 myriapods (millipeds and centipedes and symphylans), 1 pseudoscorpion, and 37 insects (4 diplurans, 1 dragonfly, 2 mayflies, 5 caddisflies, 8 stoneflies, 15 beetles, and 2 true bugs). Only 8 vertebrates are endemic to Arkansas including 5 fishes, 2 salamanders, and 1 pocket gopher (Table 1). The latest tally represents a decrease of 7 in state endemics from the 117 taxa (11 plants and 106 animals) reported by Robison and Allen (1995) to 110 documented in this report.

Table 1. Arkansas Endemic Biota.

Plants	
	Delphinium newtonianum D.M. Moore – Moore's Delphinium
	Heuchera villosa Michx. var. *arkansana* (Rydberg) E.B. Smith – Arkansas Alumroot
	Mespilus canescens Phipps – Stern's Medlar
	Quercus shumardi Buckl. var. *acerifolia* E.J. Palmer – Maple-Leaved Oak
	Hydrophyllum brownei Kral and Bates – Browne's Waterleaf
	Liatris compacta (Torr. & Gray) Rybd. – Blazing Star
	Streptanthus maculatus obtusifolius Hook – Clasping Twistflower
	Galium arkansasum var. *pubiflorum* E.B. Smith – Arkansas Bedstraw
	Polymnia cossatotensis A.B. Pittman and V. Bates – Cossatot Leafcup
	Sabatia arkansana Pringle and Witsell – Pelton's Rose-gentian
Animals	
Annelida (Oligochaeta) – Segmented Worms	*Diplocardia meansi* Gates – Earthworm
	Diplocardia sylvicola Gates – Earthworm
Mollusca (Gastropoda) – Snails and Slugs	*Somatogyrus amnicoloides* Walker – Ouachita Pebblesnail
	Somatogyrus crassilabris Walker – Thicklipped Pebblesnail
	Somatogyrus wheeleri Walker – Channelled Pebblesnail
	Amnicola cora Hubricht – Foushee Cavesnail
	Paravitrea aulacogyra (Pilsbry and Ferriss) – Mt. Magazine Supercoil
	Polygyra peregrine Rehder – White Liptooth
	Mesodon clenchi (Rehder) – Calico Rock Oval
	Mesodon magazinensis (Pilsbry and Ferriss) – Magazine Mountain Shagreen
Mollusca (Bivalvia) – Mussels and Clams	*Lampsilis powellii* (Lea) – Arkansas Fatmucket
	Lampsilis strecheri Frierson – Speckled Pocketbook
	Villosa arkansasensis (Lea) – Ouachita Creekshell
Amphipoda – Amphipods and Scuds	*Stygobromus elatus* (Holsinger) – Magazine Mountain Amphipod
	Stygobromus montanus (Holsinger) – Rich Mountain Amphipod
	Crangonyx aka Zhang and Holsinger – Amphipod
	Bacturus speleopolis Holsinger, Sawicki, and Graening – Amphipod
Isopoda – Freshwater Isopods and Pill Bugs	*Caecidotea fonticulus* Lewis – Abernathy Spring Isopod
	Caecidotea holti Fleming
	Lirceus bicuspidatus Hubricht and Mackin
	Lirceus bidentatus Hubricht and Mackin
Decapoda – Shrimps and Crayfishes	*Bouchardina robisoni* Hobbs – Bayou Bodcau Crayfish
	Cambarus aculabrum Hobbs and Brown – Benton County Cave Crayfish
	Cambaris causeyi Reimer – Boston Mountains Crayfish
	Cambarus zophonastes Hobbs and Bedinger – Hell Creek Cave Crayfish
	Fallicambarus harpi Hobbs and Robison – Ouachita Burrowing Crayfish
	Fallicambarus caesius Hobbs – Timberlands Burrowing Crayfish
	Fallicambarus jeanae Hobbs – Daisy Burrowing Crayfish
	Fallicambarus gilpini Hobbs and Robison – Jefferson County Crayfish
	Fallicambarus petilicarpus Hobbs and Robison – Slenderwrist Burrowing Crayfish
	Fallicambarus strawni (Reimer) – Saline Burrowing Crayfish
	Orconectes acares Fitzpatrick – Redspotted Stream Crayfish
	Procambarus regalis Hobbs and Robison – Regal Burrowing Crayfish
	Procambarus reimeri Hobbs – Irons Fork Burrowing Crayfish
Myriapoda – Millipeds and relatives	*Abacion wilhelminae* Shelley, McAllister and Hollis
	Boraria profuga (Causey)
	Causeyella causeyae Shear
	Causeyella youngsteadtorum Shear
	Cleidogona arkansana Causey
	Eurymerodesmus compressus Causey
	Eurymerodesmus goodi Causey
	Eurymerodesmus newtonius Chamberlin
	Eurymerodesmus polkensis (Causey)
	Eurymerodesmus pulaski (Causey)
	Hanseniella ouachiticha Allen
	Nannaria davidcauseyi (Causey)
	Nannaria depalmai (Causey)

Table 1. Continued

Myriapoda – Millipeds and relatives	*Okliulus beveli* (Causey) *Petaserpes bikermani* (Causey) *Tiganogona glebosa* (Causey) *Tiganogona ladymani* (Causey) *Tiganogona moesta* (Causey) *Tiganogona steuartae* (Causey) *Trigenotyla parca (*Causey)
Pseudoscorpionida– Pseudoscorpions	*Microcreagris ozarkensis* (Hoff)
Diplura – Diplurans	*Catajapyx ewingi* (Fox) *Occasjapyx carltoni* Allen *Podocampa inverterata* (Allen) *Clivocampa solus* (Allen)
Odonata – Dragonflies	*Cordulegaster talaria* Tennessen
Ephemeroptera – Mayflies	*Dannella provonshai* McCafferty *Paraleptophlebia calcarica* Robotham and Allen
Plecoptera – Stoneflies	*Allocapnia warreni* Ross and Yamamoto *Allocapnia ozarkana* Ross *Allocapnia oribata* Poulton and Stewart *Alloperla Ouachita* Stark and Stewart *Alloperla caddo* Poulton and Stewart *Isoperla szczytkoi* Poulton and Stewart *Zealeuctra wachita* Ricker and Ross *Leuctra paleo* Poulton and Stewart
Hemiptera – True bugs	*Acalypta susana* Allen, Carlton, and Tedder – Lace Bug *Lopidea arkansae* Knight – Plant Bug
Coleoptera – Beetles	*Scaphinotus* (s.str.) *parisiana* Allen and Carlton *Scaphinotus (Nomaretus) infletus* Allen and Carlton *Rhadine ozarkensis* Sanderson and Miller *Evarthus parasodalis* Freitag *Anillinus magazinensis* Sokolov and Carlton *Anillinus robisoni* Sokolov and Carlton *Anillinus tishechkini* Sokolov and Carlton *Hydroporus sulphurius* Matta and Wolfe *Arianops sandersoni* Barr *Arianops copelandi* Carlton *Pseudactium magazinensis* Carlton and Chandler *Pseudactium ursum* Chandler *Ouachitychus parvoculus* Chandler *Pachybrachis pinicola* Rouse and Medvedev – Leaf Beetle *Lema maculicollis* ab. *inornata* Rouse and Medvedev *Heterosternuta phoebeae* Wolfe and Harp – Predaceous diving beetle
Trichoptera – Caddisflies	*Paduniella nearctica* Flint *Paucicalcarica ozarkensis* Matthis and Bowles *Ochrotrichia robisoni* Frazer and Harris *Agapetus medicus* Ross *Helicopsyche limnella* Ross
Osteichthyes – Bony Fishes	*Noturus lachneri* Taylor – Ouachita Madtom *Noturus taylori* Douglas – Caddo Madtom *Etheostoma moorei* Raney and Suttkus – Yellowcheek Darter *Etheostoma pallididorsum* Distler and Metcalf – Paleback Darter *Etheostoma fragi* Distler – Strawberry River Orangethroat Darter
Amphibia (Caudata: Plethodontidae) – Salamanders	*Plethodon caddoensis* Pope and Pope – Caddo Mountain Salamander *Plethodon fourchensis* Duncan and Highton – Fourche Mountain Salamander
Mammalia (Rodentia: Geomyidae)– Mammals	*Geomys bursarius ozarkensis* Elrod, Zimmerman, Sudman, and Heidt – Ozark Mountain Pocket Gopher

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Algae in Agricultural Fields from St. Francis County, Arkansas

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Abstract

On August 9th, 2007, two agriculture fields (rice and sorghum fields) were sampled for freshwater algae in St. Francis County. The purpose of this study was to document the algal species in the rice and sorghum fields and compare the similarities of species composition. There were a total of 53 species identified. Overall, diatoms and cyanobacteria were equally dominant with both represented by 21 species (39.6% of the total) and 11 green algal species (20.8%) were present. The sorghum field was dominated by *Chlorogloeopsis fritschii* and *Chroococcus limneticus*, while *Anabeana cylindrica* was abundant in the rice field.

Introduction

The United States provides a large portion of the world's grain (USDA 2008a). The world grain production is $20x10^{11}$ metric tons and USA is $3.4x10^{11}$ metric tons, which is 16.8% of the world's grain production (USDA 2008a).

The world's rice production is $4.2x10^{11}$ metric tons and sorghum is $64x10^{9}$ metric tons. USA produced $62x10^{9}$ metric tons of rice and $12.8x10^{9}$ metric tons of sorghum, which is 1.5% and 12.4% of the world production of rice and sorghum production (USDA 2008a).

Arkansas is the leading producer of rice in United States at $29.7x10^{9}$ metric tons (47.9% of USA's production) and $5.1x10^{8}$ metric tons of sorghum (USDA 2008b). The economic value is over 1 billion dollars for rice and 72 million dollars for sorghum (USDA 2008b).

There have been very few or no studies of algae associated to rice or sorghum fields in USA. There is some published information available for the algal species related to terrestrial agriculture soils in United States (Shimmel and Darley 1985; Fairchild and Willson 1967; Forest et al. 1959; Schlichting 1973) but most of the rice fields studies come from India (De 1939; Roger and Kulasooriya 1980; Nayak and Prasanna 2007) and China (Wassmann et al. 1993), which are typically dominated by cyanobacteria (Forest et al. 1959).

Rice throughout the world is mainly grown under irrigated conditions. This causes nitrogen fertilizer efficiency to be low because of large nitrogen losses from flooded soils (De Datta and Buresh 1989; Ghosh and Saha 1997). To maintain the soil nitrogen pool, it is primarily fertilized with agriculture fertilizer and through biological nitrogen fixation (Kundu and Ladha 1995; Cassman et al. 1998). Cyanobacteria are extremely important to fix atmospheric nitrogen in rice fields (Roger and Kulasooriya 1980; Roger and Ladha 1992). They can contribute to the natural fertility of the soils through nitrogen-fixation (De 1939) in their heterocysts. Cyanobacteria have been used as biofertilizers and used to inoculate rice fields (Irisarri 2006). Cyanobacteria can supply approximately 4 kg/N/ha from cyanobacteria biomass to the standing crop of rice (Roger 1991).

Most published data of inoculation with cyanobacteria refer to tropical rice fields, which are different in characteristics and agriculture land management from temperate ones. Biological nitrogen fixation is far more diverse and complex in the tropics than under temperate conditions (Balandreau and Roger 1996). Assays of cyanobacterial inoculation in temperate climates were performed in the USA (Reynaud and Metting 1988).

The purpose of the study reported herein was to document species of aquatic algae and cyanobacteria associated with rice and sorghum fields from St. Frances County, Arkansas (Figure 1 and 2). As the terms are used in this paper, algae are defined as any eukaryotic organisms containing chlorophyll "a" in the Kingdom *Protista* and cyanobacteria are prokaryotic organisms containing chlorophyll "a" in the Kingdom *Bacteria*.

Methods

Site Descriptions

Plankton and sediment samples were collected from one rice and one sorghum field on August 9th, 2007. There were 3 replicate samples collected from site. Both sites there were standing water in troughs averaging 40 cm deep. Samples were collected from side of the agriculture field, no wading was involved, and the outflow from the sorghum field was not

observed. The air temperature was 43ºC. The particular sites which the samples were obtained are from St. Frances County, Arkansas (sorghum field- 34°56'47.46"N, 91°0'20.70"W and rice field- 34°57'12.44"N, 91°0'21.24"W) that are 0.76 km in distance apart (Figure 1).

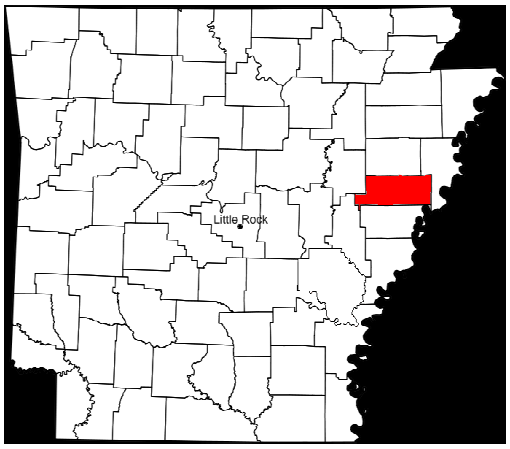

Figure 1. Locations of the two agriculture fields in St. Francis County, Arkansas.

The rice field was 22 hectares in size (Figure 2). The water temperature was 30ºC. It was disked and leveled and planted the second week of April. On May 19th, 2007, the field was fertilized with nitrogen and flooded for 2 weeks and then drained. After two weeks, the field was fertilized and flooded again and remained flooded. The field was finally drained on August 23rd and harvest started the middle of September. The yield averaged 7500 kg/hectare.

The sorghum field was 49 hectares in size (Figure 2) and the water temperature was 40ºC. It was planted on April 30 and again on May 1, 2007. Once the sorghum stalk head had bloomed, the field was irrigated in the furrows and fertilized in June. The irrigation method used followed this schedule: turn on the wells, wait until the water reached the other end of the sorghum field and stop irrigation. The field was allowed to dry out and irrigation was then repeated. They harvested in October. The yield averaged 7000 kg/hectare.

Samples were taken for plankton and sediment for identification of algal and cyanobacteria species. Plankton was collected using a Fieldmaster Mini Net 80 µm mesh from the water column and surface. Sediment was scrapped from the top 1 cm of the benthic region. The samples were collected in a sterile Whirl-pak® bag and placed in a cooler on ice (0ºC) until they were stored in the laboratory freezer. In the laboratory, algae were preserved with M3 (American Public Health Association 1992).

Figure 2. The two agriculture fields in St. Francis County, Arkansas (Google Earth).

Plankton samples were allowed to settle for concentration, while sediment samples were homogenized and mixed for slide preparation. Semipermanent slides were prepared with distilled water and sealed with epoxy (Smith, 2003). A Nikon BH-2 microscope was used at 1000X to identify algal and cyanobacteria species. Nomenclature, descriptions and keys follow Ettl & Gänter (1995), Desikachary (1959), Dillard (1989a, 1989b, 1990, 1991a, 1991b, 1993), Komárek and Anagnostidis (1999, 2005), Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b, 2000), Tilden (1910), and Uherkovich (1966).

Results and Discussion

Fifty-three species were identified from the two sampling sites (Table 1 and 2). Diatoms and cyanobacteria were equally dominant, represented by both having twenty-one species each (39.6% of the reported species) and green algae included eleven identified species (20.8%).

From the rice field, there were forty-three algal and cyanobacteria species identified, which is 81.1% of the total species identified. Diatoms were still dominant with twenty species identified (48.4% of the reported species), cyanobacteria had twelve species (27.9%) and green algae had eleven species (25.6%). Two of the twenty diatom species were planktonic and the other eighteen were benthic species, while seven green algal species were planktonic and only four were benthic.

Table 1. Annotated taxonomic list of the species of cyanobacteria and *Chlorophyta* recovered from samples collected from rice and sorghum fields in St. Francis County, Arkansas.

Taxa	Rice	Sorghum
Cyanobacteria		
Anabaena cylindrica Lemmermann	X	
Aphanocapsa fusco-lutea Hansgirg	X	
Aphanocapsa incerta (Lemmermann) Cronberg & Komárek	X	X
Aphanothece bullosa (Meneghini) Rabenhorst	X	
Aulosira fertilissima Ghose	X	
Calothrix confervicola (Dillwyn) C. Agardh	X	
Chlorogloeopsis fritschii (A. K. Mitra) A. K. Mitra et D. C. Pandey		X
Chroococcus disperses (Keissler) Lemmermann	X	
Chroococcus limneticus Lemmermann		X
Cylindrospermum marchicum Lemmermann	X	
Jaaginema geminatum (Meneghini ex Gomont) Anagnostidis & Komárek		X
Lyngbya aestuarii var. *arbustiva* Brühl & Biswas	X	
Microcystis natans Lemmermann		X
Nodularia spumigena Mertens	X	
Nostoc carneum C. Agardh	X	
Nostoc calcicola Brébisson ex Bornet & Flahault	X	
Nostoc piscinale Kützing ex Bornet & Flahault		X
Oscillatoria minnesotensis Tilden		X
Oscillatoria simplicissima (Gomont) Anagnostidis & Komárek		X
Phormidium aerugineo-coeruleum (Gomont) Anagnostidis & Komárek		X
Pseudanabaena limnetica (Lemmermann) Komárek		X
Chlorophyta		
Chara sp. 1 Linnaeus	X	
Coelastrum probiscideum Bohlin in Wittrock & Nordstedt	X	
Cosmarium granatum var. *concavum* Lagerheim	X	
Cosmarium rectangulare Grunow	X	
Cosmarium vexatum W. West	X	
Microspora stagnorum (Kützing) Lagerheim	X	
Microspora tumidula Hazen	X	
Oedogonium sp1. Link	X	
Oocystis solitaria Wittrock	X	
Scenedesmus ecornis (Ehrenberg) Chodat	X	
Scenedesmus lefevrei Deflandre	X	

There were seven heterocyst cyanobacteria species (58.3% of the cyanobacteria species identified) from the rice field samples. *Anabaena cylindrica* was abundant in the rice field, which may account for the abundance of free floating akinetes in the sample. Akinetes are resting spores to withstand adverse environmental conditions. Vegetative growth occurs from germinating akinetes (Wildman et al. 1975) as well has heterocysts (Tischer 1975). This might account for the high numbers of heterocyst species observed in the community composition. Their recruitment might come from soil akinetes, which needs to be studied further.

The sorghum field had eleven cyanobacteria and algal species identified (18.9% of the total species identified). Cyanobacteria were now dominant with ten species (90.9%) and only one diatom species (9.1%). Filamentous algae was the dominant form comprised of five species (50%) while the dominant observed species were coccoid species (*Chlorogloeopsis fritschii* and *Chroococcus limneticus*). There was only one heterocyst species found in the samples.

There was only one species (*Aphanocapsa incerta*) that was found in both agriculture fields. When ANOVA was used to compare the species similarities on the presence/absence species data, it was not surprising that the p-value was highly significant ($p=2.4x10^{-11}$). When Correspondence Analysis (CA) was run on the species data, 100% of the variation was explained by the first axes and species data separated out into distinct points (Figure 3).

Table 2. Annotated taxonomic list of the species of *Bacillariophyta* recovered from samples collected from rice and sorghum fields in St. Francis County, Arkansas.

Taxa	Rice	Sorghum
Bacillariophyta		
Achnanthes hauckiana Grunow	X	
Caloneis schumanniana (Grunov) Cleve	X	
Cocconeis placentula Ehrenberg	X	
Encyonema minutum (Hilse) D.G. Mann	X	
Fragilaria tenera (W. Smith) Lange-Bertalot	X	
Fragilaria ulna var. *acus* (Kützing) Lange-Bertalot	X	
Gomphonema augur Ehrenberg	X	
Gomphonema gracile Ehrenberg	X	
Hantzschia amphioxys (Ehrenberg) Grunow		X
Navicula cryptocephala Kützing	X	
Navicula molestiformi Hustedt	X	
Navicula subminuscula Manguin	X	
Navicula veneta Kützing	X	
Nitzschia amphibia Grunow	X	
Nitzschia fonticola (Grunow) Grunow in Van Heurck	X	
Nitzschia hantzschiana Rabenhorst	X	
Nitzschia intermedia Hantzsch	X	
Nitzschia palea (Kützing) W. Smith	X	
Nitzschia tryblionella var. *victoriae* (Grunow) Grunow	X	
Pinnularia microstauron (Ehrenberg) Cleve	X	
Sellaphora pupula (Kützing) Mereschkovsky	X	

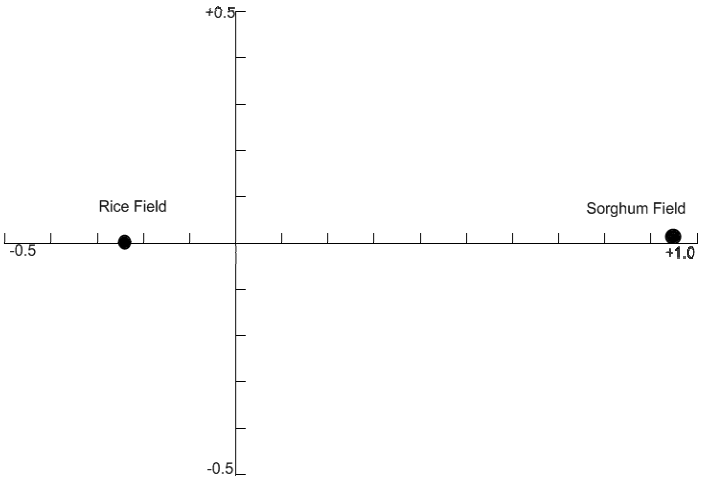

Figure 3. Correspondence Analysis (CA) conducted on the species data from the Rice and Sorghum Fields.

As a general observation, the overall study sites were diverse with respect to algal species richness, especially as a one-time sampling method. With respect to specific agriculture field assemblages of species present, the rice field was very diverse while the sorghum field was not. It was first thought both field would have similar species composition because of the close proximity of the sampling sites.

There was a 10-degree water temperature and utilization of different irrigation techniques between the two fields. This is likely the cause of the significant difference between the species assemblages. The rice field was flooded from May to August creating a more stable and homogenous and presumably less stressful environment. This in turn could allow ample time for algal colonization and increasing species diversity. The sorghum field, on the other hand, was flooded periodically, allowed to dry with higher temperatures and when needed flooded again. This may have created a higher disturbance not allowing many species to get established causing a

lower species richness and lower community diversity. This follows the Intermediate Disturbance Hypothesis model proposed by Connell (1978).

The heterocyst cyanobacteria species (*Anabaena cylindrical, Aulosira fertilissima, Calothrix confervicola, Cylindrospermum marchicum Nostoc carneum, Nostoc calcicola*) made up a large portion of the algal community in the rice field. Future research needs to be accomplished to determine nutrient (nitrogen and phosphorus) concentrations of the water throughout the growing season. In addition, other environmental factors need to be investigated to determine their importance of limiting rice (Isisarri et al 2006) and sorghum growth.

It would be of further interest to understand the environmental conditions, which promotes the colonization of heterocyst species and their significance to the rice field community. Cyanobacteria heterocyst species inoculums can be applied to agriculture fields, which need to studied, as is done other countries. The inoculums of natural biological nitrogen-fixers have the potential of increasing soil nitrogen and thus crop yield (Roger and Kulasooriya 1980) and cutting the amount of agriculture nitrogen fertilizers, thereby reducing agricultural costs.

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Compatible Stem Taper and Total Tree Volume Equations for Loblolly Pine Plantations in Southeastern Arkansas

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Abstract

A system of equations was used to produce compatible outside-bark stem taper and total tree volume equations for loblolly pine (*Pinus taeda* L.) plantations in southeastern Arkansas. Paired height-diameter stem measurements were obtained from trees located in one 45-year-old unthinned plantation. After fitting and integrating the stem taper equation to total tree height, an individual tree constant form factor volume equation was obtained. The stem taper equation can also be integrated to any merchantable height to obtain merchantable volume. To see how the constant form factor volume equation predicts outside-bark volume for trees vastly different than those used in model fitting, trees were harvested from a 17-year-old loblolly pine plantation in southeastern Arkansas. Predictions from the volume equation developed during this research were compared to three other commonly used volume equations. Validation results showed the current constant form factor equation produced the best predictions.

Introduction

Taper equations provide information about how stem diameter changes as height increases. Conversely, these equations can be used to estimate height for a given stem diameter. Thus, taper equations, when integrated, can provide estimates of volume to merchantable top limits as well as for total tree height. Compatibility between taper and volume equations is defined as when the total volume obtained by summation of the sections whose volumes are defined using the taper equation is identical to the volume calculated by the volume equation, or, more precisely, when integration of the taper equation produces the same total volume as given by the volume equation (Demaerschalk 1973). Several taper models have been developed for loblolly pine plantations throughout the southeastern US (e.g. Lenhart et al. 1987, Tasissa et al. 1997, Jordan et al. 2005, Coble and Hilpp 2006) but few have been developed exclusively for southeastern Arkansas. The objectives of this study were to estimate parameters of a taper equation for loblolly pine plantations in southeastern Arkansas that was then integrated to total tree height producing a compatible individual tree total cubic meter outside-bark volume equation. Validation analyses were conducted to determine how predictions from this newly developed volume equation compare to commonly used volume equations for trees located in southeastern Arkansas. An example is given of how to estimate outside-bark merchantable cubic meter volume to a particular upper-stem height.

Materials and Methods

Model fitting data

Equations were developed using 493 paired stem diameter-height measurements obtained from 71 trees found in five permanent research plots located in a 45-year-old unthinned loblolly pine plantation near Monticello, Arkansas. An abandoned row-cropped field was machine-planted in 1958 at a spacing of 2.44 m square using seedlings obtained from a state nursery located in Arkansas. Plots were originally established at 27 yrs. See Table 1 for a summary of tree characteristics and Figure 1 for a graphic depiction of total tree height and DBH pairs. Soils in the study area were Tippah silt loams, which are moderately well drained, with slow permeability (NRCS 2008). Slopes ranged from 0 to 4 percent, mainly southward. The climate for this area is warm and humid with annual precipitation and mean annual air temperatures ranging from 46 to 63 inches and 51° to 74°; respectively. Site index (base age 25 yr) was determined to be 18.9 m.

Estimation of the taper equation parameters

Proc Model of the SAS Institute (SAS 2003) and the Gauss-Newton algorithm were used to estimate all parameters.

Development of a constant form factor total cubic meter outside-bark volume equation

A taper equation originally developed by Kozak et al. (1969) was used to model stem diameter:

$$\frac{d^2}{DBH^2} = b_0 + b_1\left(\frac{h}{H}\right) + b_2\left(\frac{h^2}{H^2}\right) \quad (1)$$

where d is the stem outside-bark diameter (cm), h is the stem height (m), DBH is outside-bark diameter breast height (cm), H is total tree height (m), and b_0, b_1, b_2 are parameters to be estimated.

Table 1. Summary statistics of trees used to obtain stem diameter and height pairs to estimate parameters of equation (2). DBH is diameter at breast height (1.37 m aboveground), H is total tree height, and Std. dev. is the standard deviation. Number of trees was 71.

	Min	Mean	Max	Std. dev.
DBH (cm)	14.0	34.0	46.7	8.37
H (m)	12.2	24.0	29.1	3.10

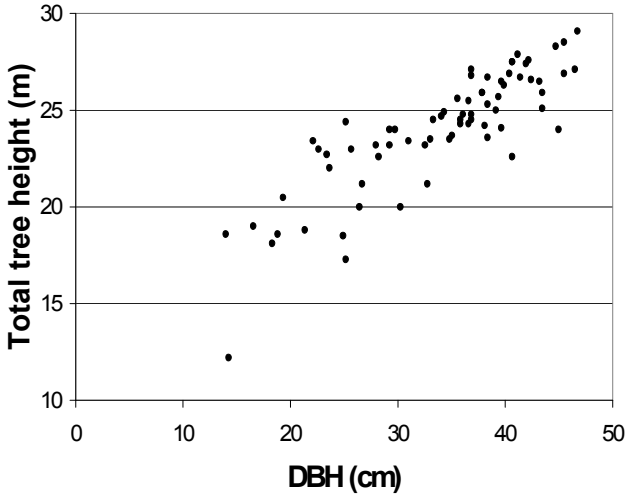

Figure 1. Scattergram of trees used to obtain stem diameter and height pairs to estimate parameters of equation (2).

Equation (1) can be rearranged:

$$d = DBH\sqrt{b_0 + b_1\left(\frac{h}{H}\right) + b_2\left(\frac{h^2}{H^2}\right)} \quad (2)$$

To obtain a total cubic meter volume equation, it must be assumed the tree bole for a particular stem diameter is circular. To get the area of the bole for that particular stem diameter, equation (3) is used:

$$Area = \frac{\pi d^2}{4(10000)} = 0.00007854\ d^2 \quad (3)$$

Where $0.00007854d^2$ derives from:

$$Area = \pi r^2 = \pi\left(\frac{d}{2}\right)^2 = \frac{\pi}{4}d^2 \quad (4)$$

Equation (4) is in square cm units since d is in cm. To obtain square meters (since we want volume in cubic meters), we need to divide the right-hand side (RHS) by 100 cm squared – 10000:

$$Area = \frac{\pi}{4(10000)}d^2 = 0.00007854\ d^2 \quad (5)$$

Total tree volume is obtained by integrating the area from equation (5) at each infinitesimal stem diameter along the entire height of the tree:

$$Volume = \int_{h_1}^{h_2} 0.00007854\ \ d^2 dh \quad (6)$$

where h_1 is stem height (m) and h_2 is stem height (m) that is greater than h_1.

The number 0.00007854 is a constant and thus equation (6) can be reexpressed as:

$$Volume = 0.00007854\int_{h_1}^{h_2} d^2 dh \quad (7)$$

By replacing d^2 in equation [7] with the square of equation [2], one obtains:

$$Volume = 0.00007854\int_{h_1}^{h_2} DBH^2\left[b_0 + b_1\left(\frac{h}{H}\right) + b_2\left(\frac{h^2}{H^2}\right)\right]dh \quad (8)$$

Where, DBH^2 is a constant and thus equation (8) can be reexpressed as:

$$Volume = 0.00007854\ \ DBH^2\int_{h_1}^{h_2}\left[b_0 + b_1\left(\frac{h}{H}\right) + b_2\left(\frac{h^2}{H^2}\right)\right]dh \quad (9)$$

After integrating equation [9], one obtains:

$$Volume = 0.00007854DBH^2\left[b_0 h + \frac{b_1}{2H}h^2 + \frac{b_2}{3H^2}h^3\right]_{h_1}^{h_2} \quad (10)$$

When h_2 is replaced by H (total tree height), and h_1 is replaced by 0, an equation to estimate total cubic meter volume is obtained:

$$Volume = 0.00007854DBH^2\left[b_0 h + \frac{b_1}{2H}h^2 + \frac{b_2}{3H^2}h^3\right]_0^H \quad (11)$$

$$Volume = 0.00007854DBH^2\left[b_0 H + \frac{b_1}{2H}H^2 + \frac{b_2}{3H^2}H^3\right] - 0.00007854DBH^2\left[b_0 0 + \frac{b_1}{2H}0^2 + \frac{b_2}{3H^2}0^3\right] \quad (12)$$

Where the RHS equation goes to 0, and after simplifying the LHS equation:

$$\text{Volume} = 0.00007854\text{DBH}^2\left[b_0\text{H} + \frac{b_1}{2}\text{H} + \frac{b_2}{3}\text{H}\right] \quad (13)$$

Equation (13) can be further simplified:

$$\text{Volume} = 0.00007854\text{DBH}^2\left[b_0 + \frac{b_1}{2} + \frac{b_2}{3}\right]\text{H} \quad (14)$$

and finally:

$$\text{Volume} = 0.00007854\left[b_0 + \frac{b_1}{2} + \frac{b_2}{3}\right]\text{DBH}^2\text{H} \quad (15)$$

After estimating parameters for equation [2] as given in Table 2:

$$\text{Volume} = 0.00007854\left[1.318172 - \frac{2.09544}{2} + \frac{0.830902}{3}\right]\text{DBH}^2\text{H} \quad (16)$$

Equation (16) can then be simplified obtaining the constant form factor total cubic meter volume equation:

$$\text{Volume} = 0.00004299\,\text{DBH}^2\text{H} \quad (17)$$

Users need to be aware that equations (10) and (17) were developed using data from only one site that was limited in terms of genetic diversity and different site preparation and cultural practices and therefore predictions may not be fully representative of their population.

Table 2. Parameter estimates for equation [2]. Std. errors are the standard errors of the estimates. Number of stem diameter and height pairs equaled 493 obtained from a total of 71 individual trees.

	b_0	b_1	b_2	Adj. R^2
Estimates	1.318172	-2.09544	0.830902	0.8876
Std. errors	0.0228	0.0563	0.0341	

Validation comparison of equation (17) to other commonly used volume equations

To help determine if equation (17) provides better estimates of volume relative to other available equations for trees located in southeastern Arkansas, an independent dataset was used for model validation. For this analysis, five loblolly pine trees found in a 17-year-old plantation planted at a spacing of 1.83 m square located on the University of Arkansas at Monticello Prisoner of War Camp forest near Monticello, AR were harvested in March 2007. In addition to the planted seedlings, the stand also contains non-planted (wildling) loblolly pine trees. This is a vastly different population of trees in terms of heights and diameters than those used in fitting equation (17). Due to the small sample size of the validation dataset, results from this analysis should only be considered indicative and not definitive as to the ability of equation (17) to predict volume for trees in southeastern Arkansas. Diameter measurements were made along the stem at DBH (1.37 m above the ground) and at 0.30 m intervals up to 3.1 m of height, at 0.61 m intervals past 3.1 m and up to 6.1 m of height, and at 1.22 m intervals past 6.1 m and to the tip of the stem. To calculate total tree volume, cubic meter volume for each separate section of the stem was calculated using Smalian's formula (Tasissa et al. 1997):

$$\text{Volume}_{\text{Segment}} = \left[\frac{\text{BA}_{\text{Large}} + \text{BA}_{\text{Small}}}{2}\right]\text{L} \quad (18)$$

where $\text{Volume}_{\text{Segment}}$ is the total outside-bark volume of the stem segment, BA_{Large} is cross-sectional basal area (square m) of the large diameter end of the segment, BA_{Small} is cross-sectional basal area (square m) of the small diameter end of the segment, and L is the length (m) of the segment.

Each separate section was then summed to obtain total tree volume. For the five validation trees, total tree height ranged from 9.4 to 13.0 m, DBH ranged from 6.9 to 11.2 cm, and total outside-bark cubic meter volume ranged from 0.017 to 0.073 m^3.

Other equations used in model validation analyses were:

$$\text{Volume} = 0.21949 + 0.00238\,\text{DBH}^2\text{H} \quad (19)$$

$$\text{Volume} = 0.002103\ \text{DBH}^{1.958489}\ \text{H}^{1.062348} \quad (20)$$

$$\text{Volume} = 0.002404\ \text{DBH}^2\ \text{H} \quad (21)$$

Equation (19) (Tasissa et al. 1997), of the combined-variable equation form, was fit using data from across the southeastern United States, equation (20) (Lenhart et al. 1987) was fit using data exclusively from east Texas, and parameters of equation (21) were estimated using the same data as those used in fitting equation (20) plus additional sources of data from east Texas. For these three equations, volume estimates are in cubic feet and were converted to cubic meters (DBH is in inches and height is in feet).

Prediction errors were compared between the three equations using the validation process proposed by Arabatzis and Burkhart (1992). The difference between the observed and predicted volume for each individual tree (e_i = [$\text{Volume}_{\text{Observed}}$ − $\text{Volume}_{\text{Predicted}}$]) was calculated for all three equations. The mean residual ($\bar{e}$) and the sample variance (v) of residuals were computed separately for each equation and considered to be estimates of bias and precision; respectively. An estimate of mean square error (MSE) was obtained combining the bias and precision measures using the following formula: $\text{MSE} = \bar{e}^2 + v$

The equation with the lowest MSE was selected as the model that best predicts volume of the trees in the validation dataset.

Results and Discussion

Only equation (17) produced a negative bias, yet the bias was smaller in magnitude than the other equations (Table 3). Based on the % Bias measure, equation (17) produced significantly better volume predictions for the trees used in model validation. It is somewhat surprising that the equations presented by Lenhart et al. (1987) and Coble and Hilpp (2006) did not perform better. The size of trees in the validation analyses was represented in their model fitting dataset and all trees used in model fitting were from east Texas.

Table 3. Validation results when predicting total outside-bark cubic meter volume for five trees located in a 17-year-old southeastern Arkansas loblolly pine plantation. The column Volume is the outside-bark cubic meter volume as determined when using Smalian's formula [equation (18)] for each segment of the stem and is considered to be the true volume.

	Volume		Tasissa et al.	Lenhart et al.	Dean and Hilpp
Tree	(m^3)	Eqn. (17)	Eqn. (19)	Eqn. (20)	Eqn. [21]
1	0.036	0.038	0.036	0.032	0.031
2	0.073	0.067	0.060	0.056	0.054
3	0.017	0.019	0.021	0.016	0.015
4	0.05	0.052	0.048	0.044	0.042
5	0.027	0.028	0.028	0.023	0.022
Average	0.041	0.041	0.039	0.034	0.033
Bias		-0.0003	0.0017	0.0063	0.0082
% Bias		-0.74%	4.19%	15.52%	19.91%
Variance		0.0000115	0.0000449	0.0000369	0.0000453

Conclusions

Based on validation analyses, equation (17) provides a reasonable alternative to other available equations when predicting total outside-bark cubic meter volume for loblolly pine plantations in southeastern Arkansas. In some cases predicting both wood and bark volume is desired because bark is often used as a fuel source. Additionally, equation (10) provides users a means to obtain outside-bark volume to any desired upper-stem merchantable height.

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Distribution and Taxonomic Status of Tarantulas in Arkansas (Theraphosidae: *Aphonopelma*)

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Abstract

The genus *Aphonopelma* (Theraphosidae) is marked by a dearth of distributional data and a problematic taxonomy. To develop occurrence information for the genus in Arkansas, I conducted a citizen-science based survey augmented by field work and examination of museum collections. Results of these efforts yielded a significant amount of data that enabled the construction of a county level map of *Aphonopelma* distribution in Arkansas; a resource hitherto unavailable. Three *Aphonopelm*a species have been described as occurring in Arkansas: *A. baergi*, *A. hentz*i, and *A. odelli*. Specimens were collected from Arkansas and Oklahoma to evaluate taxonomic and historical issues concerning the three species. Morphologically, the specimen series examined comprised a relatively homogeneous group most similar to descriptions of *A. hentzi*. In light of comparison with specimens examined for this study, species descriptions of *A. baergi* and *A. odelli* are marked by such taxonomic uncertainty as to challenge their validity and presence in Arkansas.

Introduction

Tarantulas (Theraphosidae) are among the largest and most recognizable spiders in North America. Over 50 species have been described as occurring in the United States, all within the genus *Aphonopelma* (Platnick 2008). North of Mexico, representatives of the genus range from California into Nevada, Utah, Colorado, and Kansas, southward into Arizona, New Mexico, and Texas. Portions of Missouri, Arkansas, and Louisiana represent the eastern limits of the genus.

The south-central region of the United States (Arkansas, Louisiana, Oklahoma, and Texas) contains 18 *Aphonopelma* species (Smith 1995). Taxonomy of this group of spiders is problematic. Most recognized *Aphonopelma* species in the United States were described by Chamberlin and Ivie (1939), Chamberlin (1940), and Smith (1995) from small numbers of specimens. As a result, consideration of individual variation within and among populations was limited.

Several of the characters cited in the past as comprising species-level distinctions (Chamberlin and Ivie 1939, Chamberlin 1940, Smith 1995) have since been shown to be of little indicative value (Prentice 1997). Use of dubious characters now calls into question the validity of several *Aphonopelma* species.

Three tarantula species have been reported as occurring in Arkansas, *A. hentzi* Girard 1854, *A. baergi* Chamberlin 1940, and *A. odelli* Smith 1995. *Aphonopelma hentzi* was the first tarantula species described in the United States (Girard 1854, Smith 1995). Chamberlin (1940) describes *A. hentzi* as the most common tarantula "along the valley of the Red River in Arkansas and Oklahoma, etc." With the designation of several additional *Aphonopelma* species across the region, including *A. baergi* and *A. odelli*, Smith (1995) later redefined the range of *A. hentzi* as limited to northern and central Oklahoma. This range reduction may not be justified, however. Given the aforementioned issues, it is not clear what *Aphonopelma* species actually occur in Arkansas.

Detailed information is also lacking regarding distribution of the genus across the state. Several species are still known only from their type locality and nowhere else. A problematic taxonomy coupled with a dearth of distributional data hampers efforts to conserve *Aphonopelma* species; a group of potential conservation concern. Like many other invertebrates, tarantulas have received little attention from the conservation community (Skerl 1999).

Although no *Aphonopelma* species is currently listed as endangered or threatened at the federal or state level, other tarantula genera in North America contain members who are of conservation concern. A number of *Brachypelma* species in Mexico have declined due to collection for the pet trade and habitat destruction (Locht et al. 1999). The long life spans, delayed sexual maturity, and limited dispersal abilities characteristic of tarantulas may make them especially vulnerable to such factors (Janowski-Bell 2001).

The objectives of this study were to define *Aphonopelma* distribution across Arkansas and to examine morphological variation in a preliminary effort to evaluate the taxonomic status of species listed as occurring in the state.

Materials and Methods

Distribution

In order to assess the distribution of tarantulas rapidly at a state-wide level, I developed a citizen-science effort called the Arkansas Tarantula Survey. The survey's objective was to solicit tarantula sightings from individual across the state. The survey followed the general methodology of a citizen-based effort conducted in Missouri to map tarantula distribution (Janowski-Bell 2001). The Missouri effort proved successful in generating useable distributional data over a large geographical area in a short amount of time with limited monetary expenditure.

To acquire citizen observations of tarantulas, I created a website which described the purpose of the survey, detailed how individuals could participate, and provided tools for tarantula identification. I also developed printed materials in the form of full color posters that contained information about the survey. These posters were mailed to personnel at select state parks, state wildlife management areas, national wildlife refuges, and national forests in Arkansas with the request that they be posted in areas accessible to the public. To further publicize the survey, I sought media attention through dissemination of press releases to news outlets and contacted newspaper reporters across the state.

The survey was open for public reporting from February 2004 to December 2004. That time span covers the active period for *Aphonopelma* species in Arkansas, particularly the dispersal of adult males during the fall breeding season (Baerg 1958). Individuals were asked to submit tarantula sightings either online through a web-based reporting form, e-mail, telephone, or postal service. A "sighting" was defined as the observation of an individual tarantula within a given area at one point in time. Survey participants were asked to provide their contact information, the location and date of their sighting, and a description of the spider they observed.

All tarantula sightings submitted to the survey were carefully evaluated. Particular attention was paid to descriptive information provided by respondents. In some cases, individuals would describe spiders that were obviously not tarantulas. Such sightings were omitted from the database. Sightings that lacked descriptive information of the spider observed were removed. Some individuals submitted observations of tarantulas made prior to the 2004 reporting period, those were not included either. Citizen sightings deemed valid were mapped at the county level. To augment citizen reports of tarantulas, I also conducted field surveys and searched museum collections for specimens.

Morphology

Morphological measurements of collected specimens were made in mm using a dial caliper, ±0.01 mm. Attention was focused on taxonomic characters found by Prentice (1997) to have high discriminatory value for both sexes. Leg and pedipalp measurements were made on the left side of all specimens. Trochanters and coxae were measured from their ventral aspect. All other leg measurements were taken dorsally. Carapace length was taken with anterior and posterior margins in the same horizontal plane. Carapace length is considered to the best indicator of overall size in *Aphonopelma* species (Prentice 1997). Extent of metatarsal scopulation was evaluated by using maximum extent of complete metatarsus I scopula as the proximal point for measurement in metatarsi II-IV. Palp length was calculated by adding the lengths of the femur, patella, and tibia only. Spermathecae and emboli were illustrated with aid of a stereomicroscope. All collected specimens were stored in 80% ethanol and deposited into the Arthropod Museum at the University of Arkansas.

Results and Discussion

Distribution

The citizen-survey resulted in the submission of 523 observations. Of that total, 393 observations were deemed valid sightings of tarantulas. The majority of sightings were submitted via the web-based reporting form. The first observations of tarantulas by survey participants were submitted in March 2004. In Arkansas, tarantulas are known to unseal their burrows, following overwintering, from mid-February throughout May (Baerg 1958). Number of tarantula sightings reached one of two peaks for the year in May 2004. Based on descriptions of tarantulas reported during May, most observed individuals were either females or immature males. A small number of adult males were observed as well. Observance of sexually mature males during early spring suggests either overwintering or an early maturation (Janowski-Bell and Horner 1999). Numbers of observed tarantulas declined throughout the summer months (June through August). Reported sightings increased again in September 2004.

Based on participant descriptions, the majority of tarantulas observed during September and October 2004 were adult males. Late summer into early fall in Arkansas is when sexually mature male *Aphonopelma*

leave their burrows and wander in search of mates (Baerg 1958). Once male *Aphonopelma* molt into sexually mature adults, they exhibit certain morphological traits that readily distinguish them from immatures and adult females (Baerg 1958). Adult males are almost black, with a few brown hairs on the abdomen. The carapace is a copper to gold color and the legs are quite long. Following large numbers of sightings in October 2004, observations declined into November 2004. The final sighting for the survey period was reported on 7 November 2004.

Field surveys and examination of museum collections resulted in the acquisition of 39 specimens from Arkansas and 3 from Oklahoma. Specimen localities are given below. Localities from the citizen-science survey, along with records from collected specimens, are mapped at the county level for Arkansas (Figure 1). Locations of collected specimens are listed below:

USA: ARKANSAS: *Ashley County*, Crossett, 1♂, 6 October 2004. *Boone County*, Green Forest, 1♂, 4 October 2004. *Carroll County*, Eureka Springs, 1♀, 22 May 2002. *Clark County*, Arkadelphia, 1♂, 10 October 1996; Arkadelphia, 1♂, 20 October 1997; Arkadelphia, 1♂, 17 October 1999; Jackmount, 1♂, 20 October 1997. *Cleburne County*, Heber Springs, 1♂, 26 September 2004. *Franklin County*, Altus, 1♂, 27 November 2004. *Garland County*, Hot Springs, 1♂, 16 October 1997; Hot Springs, 1♂, 28 October 1999; Hot Springs, 1♂, 28 November 1999. *Hempstead County*, Hope, 1♂, 6 October 1999. *Hot Spring County*, Bismarck, 1♂, 29 November 1999. *Howard County*, Cossatot State Park-Natural Area, 1♂, 20 October 2004. *Izard County*, Horseshoe Bend, 1♂, 18 May 2006. *Logan County*, Mount Magazine, 1♂, 7 October 2004. *Madison County*, Bear Hollow Natural Area, 1♀, 18 September 2004. *Nevada County*, Prescott, 1♂, 10 November 1991. *Pope County*, Russellville, 1♂, 16 May 1999. *Pulaski County*, Little Rock, 1♂, 2 June 2004; Maumelle, 1♀, 26 May 2004. *Saline County*, Bauxite, 3♂1♀, 17 October 2004; Benton, 1♂, 16 September 1997; East End, 1♂, 21 May 2004; East End, 1♂, 15 June 2004; Glenrose, 1♀, 2 September 2004. *Sebastian County*, Fort Smith, 1♂, 20 September 2004; Fort Smith, 1♂, 27 September 2004; Fort Smith, 1♂, 16 October 2004. *Montgomery County*, Story, 1♂, 9 September 2004. *Washington County*, Fayetteville, 1♂2♀, 21 August 2004; Springdale, 1♂, 16 September 2004. *White County*, Otte, 1♀, 6 September 2004. OKLAHOMA: *Garfield County*, 1♂, 7 June 2004. *Le Flore County*, Pawhuska, 1♂, 14 September 2004. *Osage County*, Pocola, 1♂, 27 September 2004.

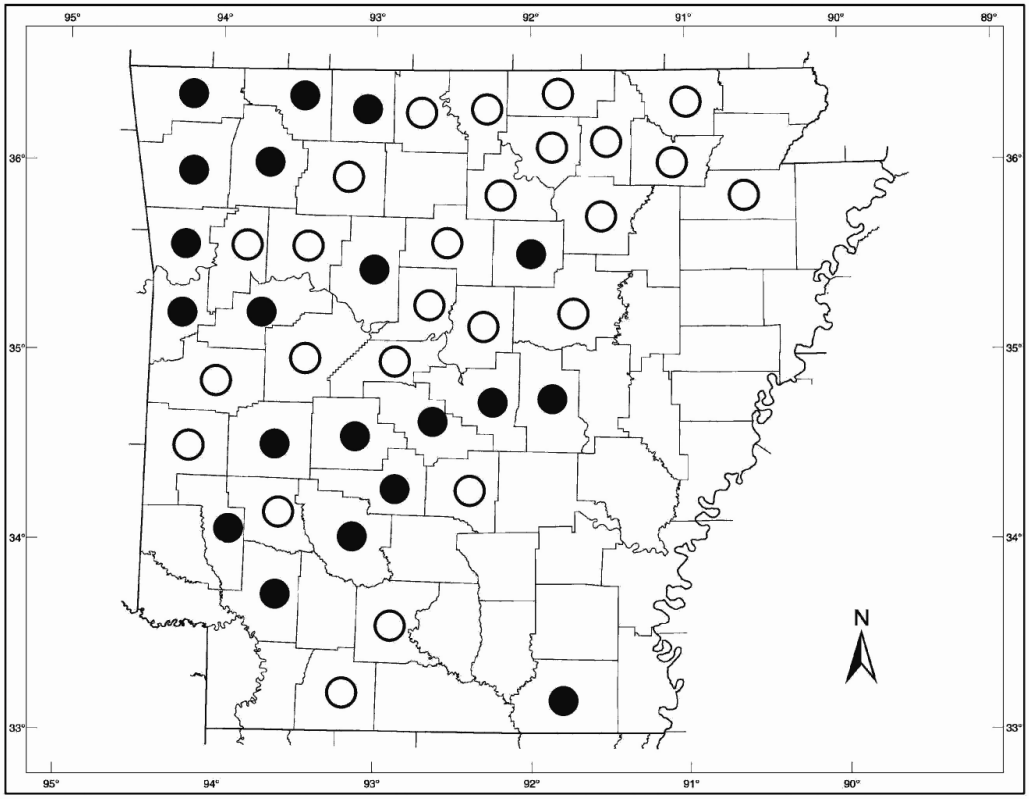

Figure 1. Distribution of *Aphonopelma* in Arkansas. Solid circles represent counties for which both a voucher specimen and sight observation exist. Open circles signify those counties with sight records only.

Most tarantula observations submitted by participants were clustered around population centers within the state. Tarantulas were most often reported from a respondent's private property. Since observations were clustered, less densely populated areas of the state may not have been as well sampled. While this bias does impose limits on the data, the use of citizen observations in this case made it possible to generate distributional data over a very short time frame and at a low cost. While certainly incomplete in scope, generating comparable distributional data through a more formalized effort would have required significant expenditures of both time and financial resources.

Morphology

A total of 8 adult females and 26 adult males were secured from Arkansas. Three adult males were obtained from localities within the putative range of *A. hentzi* in Oklahoma as well. A small number of specimens were found in museum collections, but due to varying states of condition, were not included in the morphological assessment. Type specimens of *A. baergi* (American Museum of Natural History), *A. odelli* (Oklahoma State University), and *A. hentzi* (Oklahoma State University) were not examined.

Larger numbers of males than females were obtained as the former leave their burrows upon maturity and wander in search of females making them more conspicuous and hence easier to collect. Adult females are more difficult to locate, as they are more sedentary in comparison to males.

Adult female and male *Aphonopelma* from Arkansas, and adult males from Oklahoma, form a relatively homogenous group in terms of carapace and leg lengths (Table 1). Range values established for these measurements overlap significantly especially as far as males from Arkansas and Oklahoma are concerned. On average, scopulation covered roughly one-third of metatarsus IV for all specimens collected from Arkansas and Oklahoma. Specimens of both genders were also typified by undivided scopula and hairlike setae on the prolateral face of coxa I.

Spermathecal structure for all female specimens examined exhibited little variation (Figure 2). All 8 specimens possessed spermatheca separated and with capitate bulbs, typical of the genus *Aphonopelma* (Prentice 1997). Spermathecae did exhibit slight variability in height but were marked by an overall structural consistency.

Male emboli displayed little variation as well for specimens collected from Arkansas and Oklahoma (Figure 3). All males displayed slender emboli with weakly developed apical and prolateral inferior keels at the distal tip.

The legs of adult males from Arkansas and Oklahoma were clothed in black pubescence. Abdomens were characterized by short black hairs interspersed with longer brown setae. The carapace of males ranged from light brown to copper in coloration. The legs of adult females ranged from dark brown to black in color. The abdomens of females were generally covered in dark brown setae while carapaces were light brown in color.

Table 1. Carapace, leg, and metatarsal values for Arkansas and Oklahoma *Aphonopelma* along with values for holotype and paratype specimens (means, SD). LC = carapace length, LAI, LAII, LAIII, LAIV = length of legs I, II, III, and IV, ScMIV (%) = percent scopulation of metatarsus IV.

	Arkansas ♀ [*n* = 7]	AR ♂ [*n* = 26]	OK ♂ [*n* = 3]	*A. hentzi* [holotype ♂]	*A. hentzi* [paratype ♀]	*A. baergi* [holotype ♀]	*A. odelli* [holotype ♀]
LC	16.72-19.74 (18.35, 1.09)	12.03-18.36 (15.00, 1.33)	15.88-17.51 (16.66, 0.82)	15.00	20.00	36.00	21.00
LAI	51.35-63.54 (59.15, 4.46)	52.38-67.30 (60.39, 3.97)	63.83-68.25 (65.70, 2.29)	48.00	47.00	82.80	47.00
LAII	50.84-61.83 (54.84, 4.14)	48.47-67.23 (57.74, 3.92)	61.60-64.30 (62.65, 1.45)	46.00	44.00	73.70	43.00
LAIII	49.14-58.55 (52.99, 3.60)	46.70-64.49 (54.46, 3.67)	57.07-61.44 (58.84, 2.30)	42.00	40.00	71.30	41.00
LAIV	55.90-67.03 (62.38, 5.05)	54.05-75.50 (64.99, 4.57)	66.22-71.96 (69.19, 2.88)	52.00	51.00	81.80	51.00
ScMIV (%)	30-40 (37.50)	30-47 (37.65)	30-44 (34.67)	35	--	--	52

Status of Aphonopelma baergi

Aphonoplema baergi was described by Chamberlin (1940) from a single adult female taken from the collection of William J. Baerg, a noted figure in North American arachnology (Peck 1981). The type locality is Fayetteville, Washington County, Arkansas. No other localities for the species have been published. Although the type specimen of *A. baergi* was purportedly taken from Baerg's own Fayetteville, Arkansas study site, evidence suggests otherwise (Smith 1995).

Chamberlin (1940) states that the species is "readily distinguishable from others known from the United States by its large size, coloration, and the spacing and proportions of the eyes." The *A. baergi* type specimen is atypically large, with a carapace length of 36 mm. Smith (1995) cites the carapace length of the type specimen as 28 mm. Chamberlin (1940) does reference an immature female as being taken from the same locality as the type. Smith (1995) must have examined the immature specimen instead of the actual type. This proposition is supported by the fact that leg lengths cited by Smith (1995) for the *A. baergi* type are significantly less than those described by Chamberlin (1940). In light of that, measurements provided in Table 1 for *A. baergi* are based on values from Chamberlin (1940).

Baerg (1958) lists carapace measurements of 3 adult females from his Fayetteville study site as between 17 to 21 mm. The average carapace length of 2 adult females taken from within Fayetteville, Arkansas for this study was 19.40 mm. The average carapace length for 6 additional adult females collected elsewhere in Arkansas was 18.2 mm. The average carapace length for 8 south-central United States *Aphonopelma* species with female types is 20.10 mm; carapace lengths taken from Smith (1995). The female paratype of *A. hentzi* has a reported carapace length of 20 mm (Smith 1995). The measurements cited for adult (Chamberlin 1940) and immature individuals (Smith 1995) are clearly outside the normal size range for *Aphonopelma* in the south-central United States.

While carapace length is a relatively objective taxonomic character, the other characters highlighted by Chamberlin (1940) as distinguishing *A. baergi*, coloration and spacing and proportions of eyes, are more subjective in nature. The coloration of *A. baergi* was described by Chamberlin (1940) as "deep chocolate brown, nearly black. Long hairs of legs mostly similar color, but in part, on posterior pairs more especially rust-colored. Long setae of abdomen rust colored." While this color pattern could roughly approximate that of specimens found in Arkansas, it could also be applied to a number of other species across the south-central United States. The use of coloration in and of itself can be quite subjective and dependent upon time since last molt (Prentice 1997). In addition, differences in the spacing and proportion of eyes, cited by Chamberlin (1940) as defining characters for a number of *Aphonopelma* species, have been found to be highly variable and to constitute artificial differences (Prentice 1997).

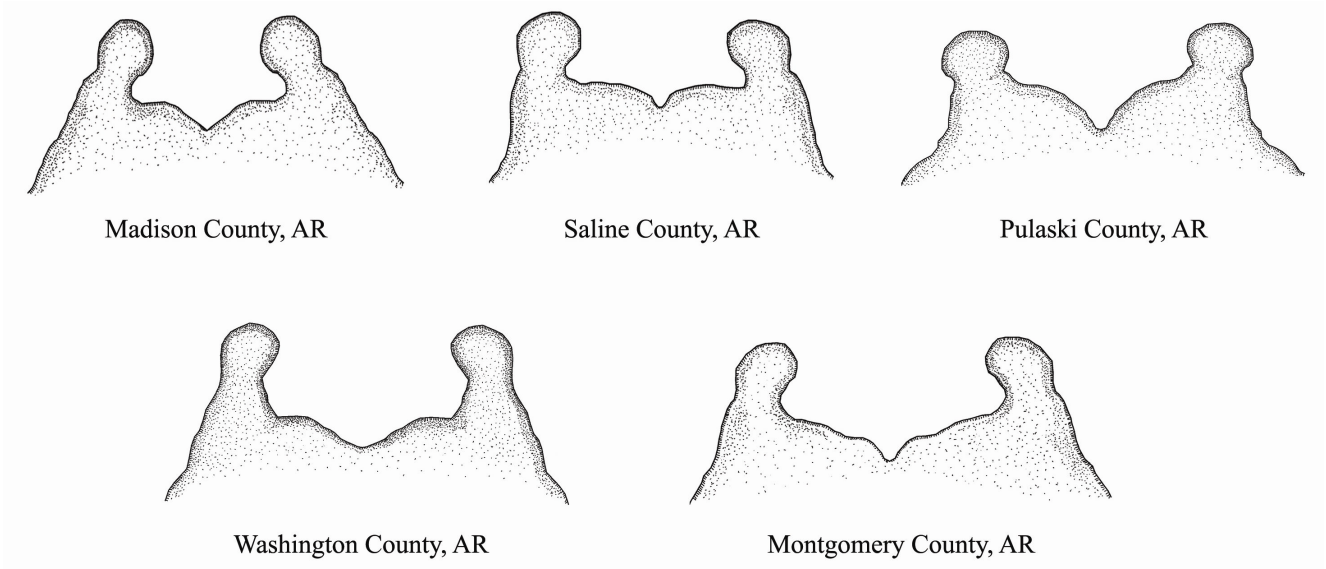

Figure 2. Representative spermathecae of female *Aphonopelma* collected in Arkansas.

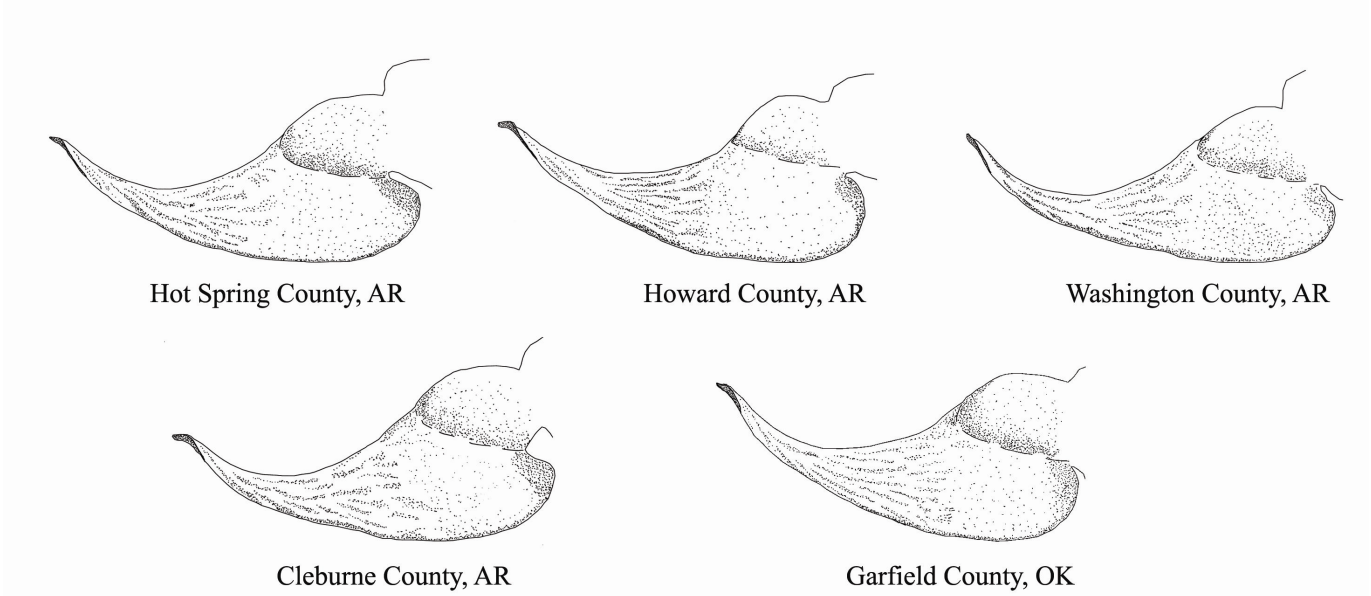

Figure 3. Representative emboli of male *Aphonopelma* collected in Arkansas and Oklahoma.

For the adult *A. baergi* type, Chamberlin (1940) estimated scopulation as covering approximately one-quarter of metatarsus IV. Conversely, Smith (1995) illustrates scopulation extending to nearly half (40%) of metatarsus IV on the immature specimen. The specimens examined for this study exhibited a relatively wide variation in metatarsal IV scopulation (Table 1). I found variation in this character as great for male and female specimens collected from the same locality as those from different locales. Review of larger numbers of specimens obviously allows for greater consideration of individual variation both within and among populations.

Chamberlin (1940) did not describe the spermatheca of *A. baergi*. Smith (1995) examined this structure, in what must be assumed was the immature specimen, and noted that it possessed a single fused spermatheca, a trait characteristic of the genus *Brachypelma* (Locht et al. 1999). The genus *Aphonopelma* is typified by paired spermatheca separated and with capitate bulbs (Prentice 1997). Smith (1995) concluded that the specimen "is patently not a mid-west grassland Theroaphosid" and that it "has all the taxonomic characteristics of the genus *Brachypelma*." Smith (1995) postulated that Baerg may have accidentally labeled a *Brachypelma* specimen collected from Mexico, a country in which Baerg had travelled and collected, as an *Aphonopelma* from his Arkansas study site.

The use of spermathecal structure for defining *Aphonopelma* species has been cautioned (Prentice 1997) but is relevant here as the *A. baergi* type deviates so strongly from the generic norm. None of the females examined for this effort possessed a fused spermatheca, rather all possessed separated twin seminal receptacles. These spermathecae were compared to descriptions and illustrations of the female paratype of *A. hentzi* from Smith (1995). Comparisons indicate that the spermathecae of females from Arkansas are similar to those illustrated by Smith (1995) for *A. hentzi* and *A. odelli*; basal segment narrow and high with two oval seminal receptacle heads with tapering necks. My results support the supposition that the *A. baergi* type specimen is strongly atypical of any known *Aphonopelma* species in the United States and is probably a mislabeled specimen taken from a locality outside of the United States.

Status of Aphonopelma odelli.

Smith (1995) described *A. odelli* from a single female collected in McCurtain County, Oklahoma. The distribution of *A. odelli*, as described by Smith (1995), is "centred on the Ouachita forest region of south east Oklahoma and western and central Arkansas." Smith's (1995) assertion that *A. odelli* ranges into Arkansas is based on a female specimen, housed in the American Museum of Natural History (AMNH), that purportedly shares a specific structural characteristic in common with the McCurtain County type. According to Smith (1995), the AMNH specimen was collected from Imboden, Arkansas. That specific locality is problematic as Imboden is in Sharp County, situated in the Central Plateau of the Ozark

Highlands, many kilometers to the northwest of the Ouachita Mountains (Woods et al. 2004).

The species primary distinguishing features are listed by Smith (1995) as shortened seminal receptacles of the spermatheca and extent of scopulation on metatarsus IV. As stated above, no significant variations in spermatchecal structure were noted among the specimens collected in Arkansas for this effort. The spermatheca of *A. odelli*, as illustrated by Smith (1995), is within the range of variation exhibited by the specimens I examined and is similar to that illustrated for the female paratype of *A. hentzi* (Smith 1995).

Smith (1995) described metatarsus IV of *A. odelli* as being scopulate over half its length. A feature, which Smith (1995) states, separates this species from *A. hentzi* in which one third of metatarsus IV is scopulate. Percentage of scopulation on metatarsus IV for female specimens collected during this study from Arkansas averaged 37.5%. The upper range values established for metatarsal IV scoupulation generated here (Table 1) approach what could be considered nearly half. There was no geographic relationship among specimens I examined in terms of extent of metatarsal IV scopulation; individuals from widely separated locations within Arkansas shared identical values. My results suggest that the characters used by Smith (1995) do not constitute sufficient criteria to define the *A. odelli* type as a species distinct from *A. hentzi*. Rather, the specimens examined by Smith (1995) most likely display variation of traits at the individual rather than species-level.

Status of Aphonopelma hentzi

Aphonopelma hentzi was described by Girard (1854) from specimens collected along the route of Randolph B. Marcy's exploration of the Red River (Marcy 1854). Girard's description of this species is of limited value in terms of determining what constitutes *A. hentzi*. Further confounding the issue is that the final disposition of Girard's type specimen is unknown (Smith 1995). Smith (1995) later designated a male neotype and a female paratype for the species using specimens collected from central Oklahoma.

In an attempt to assess the actual location of Girard's type, Smith (1995) states that "we only have a very approximate idea of the likely location site" and that "My own view is that the material was collected in 1851…in the region of McLain County in late August." The current male neotype and female paratype of *A. hentzi* were collected from Garfield County, Oklahoma. Smith (1995) also designated specimens from Cherokee, Pawnee, Payne, and Tulsa Counties, Oklahoma as *A. hentzi*.

Contrary to Smith (1995), if one examines Girard (1854), he writes that the type specimen of *A. hentzi* was collected on 17 May 1852 during Marcy's Red River expedition. Girard (1854) states that the type was taken "on an open, barren prairie between Camps 2 and 3." According to Marcy (1854), the expedition was to begin at "…the mouth of Cache Creek (the initial point of reconnaissance upon Red River)." Cache Creek empties into the Red River in what is today Cotton County in southwestern Oklahoma. The expedition arrived at its starting point, the mouth of Cache Creek, on 13 May 1852 and established camp.

The party departed 16 May 1852, travelled a little over 14 miles between Cache Creek and the Red River, and established a second camp near "a small affluent of the west fork of Cache Creek." During that same day, Marcy noted that the Wichita Mountains were clearly observable 25 to 30 miles to the north. On 17 May 1852, the expedition travelled 11 additional miles, and again camped near Cache Creek, their third camp. Based on the distances travelled between Cache Creek and the Red River and the reference to the Wichita Mountains, Girard's type specimen was collected somewhere in Cotton County, Oklahoma.

The male neotype and female paratype designated for this species by Smith (1995) do provide a basis for comparison with data reported here. Smith (1995) described and illustrated the embolus of the male neotype *A. hentzi* as a "typical tapering embolus" with a "small shallow keel at apex." A key feature Smith (1995) noted in delineating those species with male types was variation in the basal division of the palpal bulb. Prentice (1997) reported minor variation in this structure for Mojave Desert *Aphonopelma* and reported what variation did exist was as great intraspecifically as interspecifically. As a result, Prentice (1997) considered variation in this character to be of doubtful indicative value for species delineations.

The emboli of all male *Aphonopelma* examined herein (Figure 2) exhibited little structural variation in structure, including the basal division. A comparison of these emboli to the illustration of the embolus of *A. hentz*i from Smith (1995) yielded no substantive differences. Comparisons of spermathecal structure to that illustrated by Smith (1995) for *A. hentzi* likewise exhibited little variation. Smith (1995) estimated scopulation as covering approximately one third of the male neotypes' metatarsus IV; a value consistent with the specimens collected during this study.

Conclusions

The use of a citizen-science based survey proved effective for generating usable distributional data for

tarantulas in Arkansas. With little cost, a significant amount of information was obtained over a short time frame. This data provided the first opportunity to map the distribution of *Aphonopelma* across the state.

The taxonomic portion of this work was not intended to be exhaustive, but rather to simply focus on specific taxonomic traits listed by others as defining *Aphonopelma* species in Arkansas. Certain factual errors within these species descriptions also needed to be addressed. Based on the series of specimens I examined, *Aphonopelma* in Arkansas are a morphologically cohesive group. Individuals did exhibit variation in certain traits but not to such a degree as to represent species-specific differences.

The presence of *A. baergi* in Arkansas and its status as a valid species are in doubt. The type specimen possesses traits that set it apart from any other known *Aphonopelma* species in the United States. Further, specimens collected near that species type locality were more similar to descriptions of *A. hentzi* in Smith (1995).

Based on my review of several specimens, the characters cited as defining *A. odelli* from other *Aphonopelma* species are most attributable to individual variation. Traits described for *A. odelli* do not differ markedly from those observed in recently collected material in Arkansas and Oklahoma, which in turn are similar to what is considered to be *A. hentzi* by Smith (1995). The limited sample size used to describe *A. odelli* severely hampered consideration of individual variability and inadvertently resulted in the application of artificial characters. Thus, the validity of *A. odelli* as a distinct species is also much in doubt. Based on my review of Arkansas and Oklahoma specimens, all material I examined should best be diagnosed as *A. hentzi*.

Acknowledgments

I would like to thank the hundreds of Arkansans who took part in this citizen-science study. Their efforts were critical to this effort.

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Historical Forest Landscape Changes in the Buffalo River Sub-Basin in Arkansas

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Abstract

Forested areas in the United States have been altered since the time of European settlement. For this reason, research interests have increased in comparing present day vegetation with that of the pre-Euroamerican era to see what changes, if any, have occurred in some of our more outstanding natural areas. Such studies have been conducted in other parts of the United States but limited research has been done in Arkansas. The General Land Office (GLO) surveys of Arkansas were originally conducted between approximately 1815 and 1850 shortly after Arkansas was acquired from France by means of the Louisiana Purchase and provides the only systematic on-ground survey in Arkansas that predates most formal botanical investigations. The GLO surveys used witness trees to define the location of section corners and lines. Descriptions of witness trees included tree species and diameter along with distance and direction to the section corner or line. This historical GLO data was compared to United States Forest Service (USFS) Forest Inventory and Analysis (FIA) data, which represent present vegetation conditions for 62 townships in the Buffalo River Sub-basin. Comparisons indicated that eastern red cedar (*Juniperus virginiana*) increased from 0.7% to 7.8% of the total forest species in the sub-basin, hickory (*Carya spp.*) increased from 8.2% to 14.3%, while oak (*Quercus spp.)* species decreased from 43.0% to 30.1%. Based on this study it appears that post-Euroamerican settlement fire suppression and agricultural practices in addition to other human activities has caused vegetation changes in this area.

Introduction

In 1972, Congress established the Buffalo River as the first National Scenic River in the United States. It is one of the few remaining free-flowing rivers in the lower 48 states beginning in the Boston Mountains of Arkansas and emptying into the White River near Buffalo City, Arkansas. The watershed currently consists of open farmlands, forests, abandoned home sites and small urban areas.

Native Americans have lived in the area for over 10,000 years (USDA 1999a). It is believed that the present tree species occupying the watershed were established approximately 5,000-6,000 years ago after stabilization of climate following the last ice age (USDA 1999a). European settlement in the Ozarks began in the late 1820's and is evident by place names and by many abandoned settlements. Beginning in the early 1900's, fire suppression is believed to have altered tree species composition by favoring less fire-tolerant species (Schroeder 1981, Guyette and McGinnes 1982). Agricultural practices and other human activity since settlement have also significantly impacted tree species composition (Abrams 1998, USDA 1999b).

The Buffalo River Sub-basin represents one of the few remaining pristine waterways in this country, making it an area of great conservation concern. By comparing past and present vegetative conditions it may be possible to understand at least some of the changes that have occurred. For these reasons we implement a study which analyzes pre-Euroamerican Landscape within the Buffalo River Sub-basin. Thus, the objectives of the study were to compare major pre-Euroamerican species groups found in the Buffalo River Sub-basin using the General Land Office (GLO) Surveys and the United States Forest Service (USFS) Forest Inventory and Analysis (FIA) data to see what changes have occurred over time.

Previous work using General Land Office Surveys

Numerous studies in other parts of the United States have used GLO notes to analyze and compare present day vegetation with pre-Euroamerican vegetation. An incomplete listing of studies includes those conducted in Ohio (Whitney 1982), Texas (Schafale and Harcombe 1982), Iowa (Anderson 1996), Pennsylvania (Abrams and Ruffner 1995), Wisconsin (Dorney and Dorney 1989, Manies and Mladenoff 2000, Sickley et al. 2000), Illinois (Fralish et al. 1990, Leitner and Jackson 1980), Michigan (Palik and Pregitzer 1992, Zhang et al. 2000), Louisiana (Delcourt 1976), New York (Loeb 1987), New Jersey (Russel 1981, Loeb 1987), Vermont (Siccama 1971) and West

Virginia (Abrams and McCay 1996). Most of these studies used the GLO notes to develop species lists to determine pre-Euroamerican forest composition.

In Michigan, Palik and Pregitzer (1992) found major differences between pre-Euroamerican and modern vegetation among two different landscapes. These included areas that were dominated by fire sensitive eastern hemlock (*Tsuga canadensis*) and American beech (*Fagus grandifolia*), and areas dominated by fire-dependent red pine (*Pinus resinosa*), white pine (*Pinus strobus*) and jack pine (*Pinus banksiana*). Soil types in the two areas were fairly similar, but disturbance frequency was thought to be quite different based on the GLO survey information. Thus, without human intervention the areas were historically quite different due to differences in microclimate and location. However, both these landscapes have become dominated by bigtooth aspen (*Populus grandidentata*), red oak, and red maple, all of which had been of minor importance in the historical surveys.

Another study (Zhang et al. 2000) investigated vegetation change in the Upper Peninsula of Michigan. The authors found there was very little difference between the composition of the pre-Euroamerican forests and those of the present. Although the species mix was not found to be significantly different, differences in stand density were found. In addition, there was more fragmentation of remaining forestlands and open lands due to human settlement (Zhang et al. 2000).

Little research has been done in Arkansas using the GLO surveys. Foti and Glenn (1990) used the GLO notes in the Ouachitas and Tucker (1990) used the GLO notes in the Ozarks to analyze pre-Euroamerican vegetation and compare it to present conditions. Bragg (2002, 2004a, 2004b) used GLO notes to understand the historical vegetation in western Arkansas and Ashley County Arkansas. However, no GLO-based research has been done specifically for the Buffalo River sub-basin.

Accuracy of General Land Office Surveys

Accuracy and detail of the GLO notes varied depending on the surveyor. Occasionally there were cases of fraud where surveyors would supposedly survey areas in the time it would normally take a person to walk that distance (sometimes even faster). This problem was reported by Lucious Lyon, the Surveyor General for Ohio, Indiana, and Michigan. Lyon is quoted as saying the return for many townships were "grossly fraudulent-the greater portion of the field notes there being wholly fictitious or descriptive of lines and corners that were never established." Lyon stated that at least 150 townships in Lower Michigan would need to be redone due to fraud (Stewart 1935).

More common, however, were cases of negligence and carelessness, where resurveys showed that corner and line trees were not where they were described in the notes. For example, quarter corners on east-west lines were required to be run at random from a section corner to the corner 1.6 kilometers east and then run back for correction. There are many instances reported where surveyors merely set the new corner directly without going back and offsetting the random line appropriately based on the error (Bourdo 1956).

There are other factors that affect the accuracy of the GLO notes. One is that selection of bearing and witness trees was biased by the surveyors, and therefore may not be representative of forest conditions. In Michigan, for example, Bourdo (1956) reported that surveyors chose healthy trees generally, from 25 to 40 cm in diameter, as it was believed these trees provide more permanent marks than smaller or larger trees. There is also some suspicion that certain types of trees may have been favored by some surveyors. This may have been the case in northern Louisiana where Delcourt (1976) interpreted the greater-than-average distance from section corners to pine witness trees as suggestive of a preference for pines over hardwood trees.

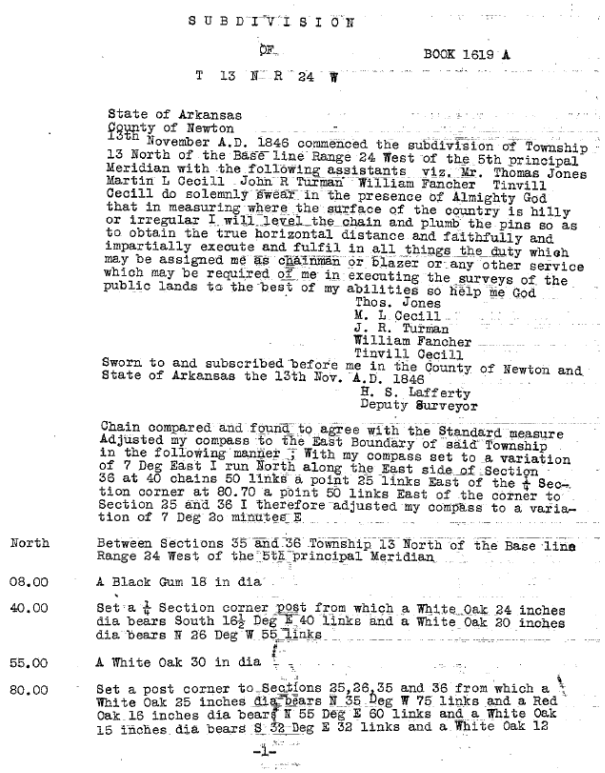
Finally, there were great differences in how surveyors recorded what they observed. Some surveyors provided much more detail than did others (Hutchinson 1988, Tucker 1990). Despite these problems, the GLO notes provide us with one of the most systematic on-ground surveys, and in most cases the only inventory of vegetation before Euroamerican settlement.

Material and Methods

The study area consists of 62 townships, each of which covers approximately 6 by 6 miles. Townships were selected if they encompassed any portion of the Buffalo River Sub-basin. The sub-basin is located in north central Arkansas and encompasses most of Newton and Searcy Counties as well as portions of Marion, Boone, Madison, Pope, Van Buren, Stone and Baxter Counties. Of the total area, 38,447 ha are managed by the National Park Service under the National Scenic Rivers Act of 1972. The Buffalo River is approximately 190 kilometers long and begins in the Boston Mountains of Arkansas and empties into the White River near Buffalo City, Arkansas.

General Land Office surveys in Arkansas began on October 27, 1815 with the initial survey of the Fifth Principal Meridian at the confluence of the Arkansas

and Mississippi Rivers by Prospect C. Robbins after Arkansas was acquired from France by means of the Louisiana Purchase (Anderson 1996). Surveys in the Buffalo River sub-basin were done between 1830 and 1847 by 18 different surveyors. These surveys included descriptions of topographic features and vegetation cover. Along with tree common names and estimated tree diameters, the GLO notes gave the exact bearing and distances to witness trees from every section corner (Figure 1).



SUBDIVISION

OF BOOK 1619 A

T 13 N R 24 W

State of Arkansas
County of Newton
13th November A.D. 1846 commenced the subdivision of Township 13 North of the Base line Range 24 West of the 5th principal Meridian with the following assistants viz. Mr. Thomas Jones Martin L Cecill John R Turman William Fancher Tinvill Cecill do solemnly swear in the presence of Almighty God that in measuring where the surface of the country is hilly or irregular I will level the chain and plumb the pins so as to obtain the true horizontal distance and faithfully and impartially execute and fulfil in all things the duty which may be assigned me as chainman or blazer or any other service which may be required of me in executing the surveys of the public lands to the best of my abilities so help me God

Thos. Jones
M. L Cecill
J. R. Turman
William Fancher
Tinvill Cecill

Sworn to and subscribed before me in the County of Newton and State of Arkansas the 13th Nov. A.D. 1846

H. S. Lafferty
Deputy Surveyor

Chain compared and found to agree with the Standard measure Adjusted my compass to the East Boundary of said Township in the following manner ; With my compass set to a variation of 7 Deg East I run North along the East side of Section 36 at 40 chains 50 links a point 25 links East of the ¼ Section corner at 80.70 a point 50 links East of the corner to Section 25 and 36 I therefore adjusted my compass to a variation of 7 Deg 30 minutes E

North Between Sections 35 and 36 Township 13 North of the Base line Range 24 West of the 5th principal Meridian

08.00 A Black Gum 18 in dia

40.00 Set a ¼ Section corner post from which a White Oak 24 inches dia bears South 16½ Deg E 40 links and a White Oak 20 inches dia bears N 26 Deg W 55 links

55.00 A White Oak 30 in dia

80.00 Set a post corner to Sections 25,26,35 and 36 from which a White Oak 25 inches dia bears N 35 Deg W 75 links and a Red Oak 16 inches dia bears N 55 Deg E 60 links and a White Oak 15 inches dia bears S 32 Deg E 32 links and a White Oak 12

-1-

Figure 1. General Land Office field notes (Arkansas Commissioner of State Lands 1999).

A script was written in ArcView to enter the GLO plat map and field notes into a Geographic Information System (GIS) layer referenced to a true coordinate system. The script used a quarter section data layer created by the authors. The first script allows the user to select a section corner or quarter section post (with known coordinates) and type in the bearing and distance of the trees from the known points. This produced a tree (point) layer in the GIS. For line trees a second script was first used that computes the bearing and distance along the section line. Once this was done, the first script could be used and the "Already Selected" option could be selected in the "Quadrant" window to call the bearing from the other script. The fields that are associated with the tree data included Diameter, UTM X and Y coordinates, Species, Quadrant, Azimuth Angle, Distance, Surveyor, Survey Date, Township, Slope, Elevation, and Aspect. The GLO GIS database for the sub-basin included more than 25,000 trees (points).

Another objective of this study was to determine if there were spatial changes by species/species group in regards to slope, elevation and aspect. Slope and aspect were calculated by the GIS using a 30-meter USGS digital elevation models (DEM) for each tree (point). The species groupings were essentially the same as that used for species composition and diameter distribution analysis. Some of the less common tree species were not included in this analysis.

In order to test for surveyor bias, it was necessary to determine if the average distance to each surveyed tree species groups were statistically similar or different from the average distance of other species groups. In order to accomplish this, only trees demarcating section corners were used. Trees along section lines were excluded as they had a fairly predictable intentional spacing of approximately 400 meters. Surveyor bias was analyzed using an analysis of variance with completely randomized design and multiple comparison tests as suggested by Delcourt (1976). All tests were analyzed at an alpha level of 0.05. There are weaknesses in this method of testing surveyor bias as discussed by Grimm (1981) and Whitney and DeCant (2001). Multiple comparison tests were done included the Bon Ferroni Approach, Fisher's LSD, Tukey's HSD, Student-Newman-Keuls and Duncans Multiple Range Test to test surveyor bias.

To determine the present vegetation types in the Buffalo River Sub-basin FIA data from 1999 in the Sub-basin was used. The FIA program (initially known as the Forest Survey) was conceived over eight decades ago by the Congress of the United States. Data from 1999 was used because it included global positioning system (GPS) plots in which points for all trees could be calculated and mapped in a GIS layer. This data layer had more than 1,800 trees.

Results

General Land Office Surveyor Biases

The only species group with a significantly different average distance was walnut/hickory, which was significantly less than average. All other groups were statistically similar to each other. This may suggest either a bias against walnut/hickory, or it may indicate a greater density for this particular group.

Species Composition Comparisons

All trees in the sub-basin were included for this analysis from both time periods. Species were grouped

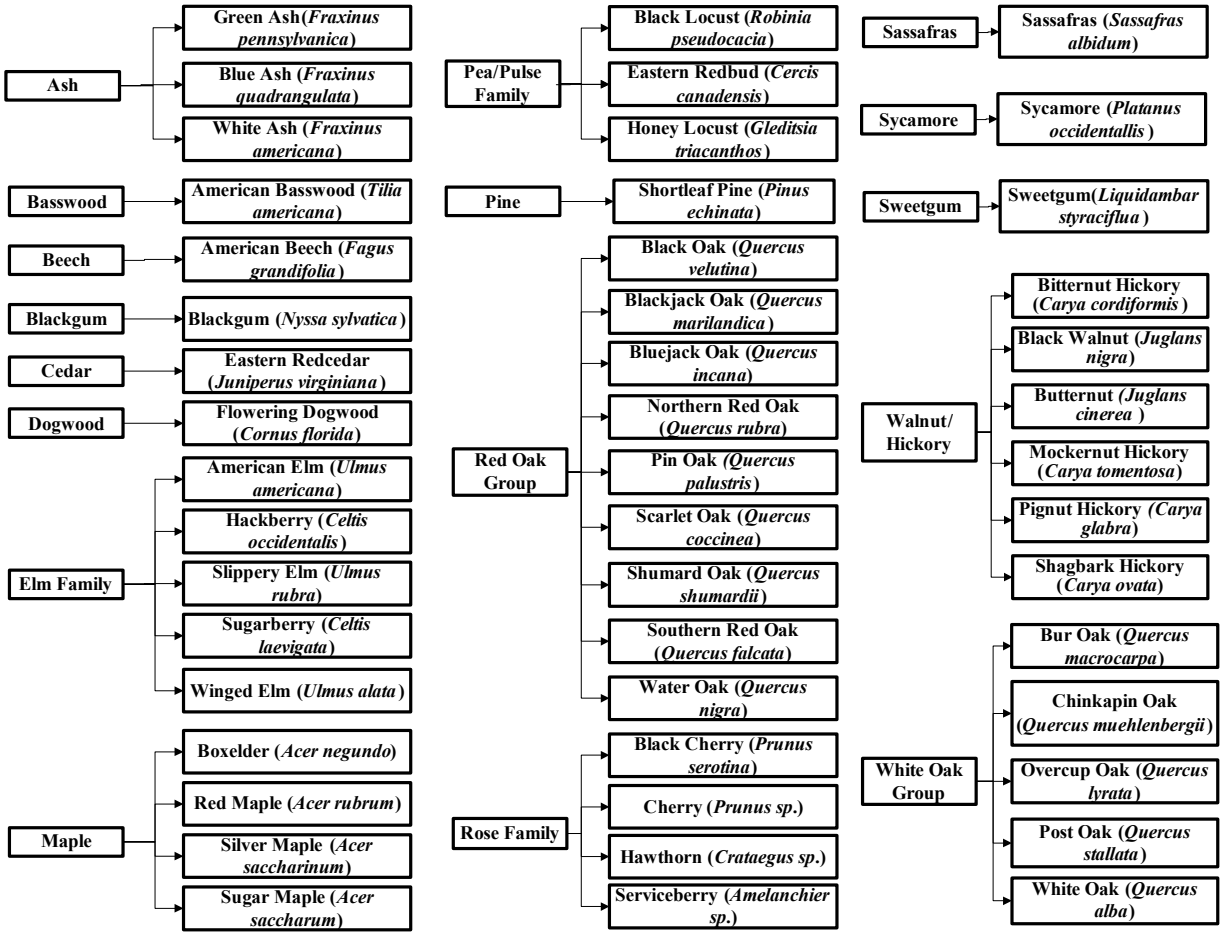


Figure 2. Study species groupings.

for species composition analysis based on individual species characteristics and taxonomic classifications. In the case of some of the less common tree types, it was necessary to group them into family groupings (Figure 2).

Diameters for the FIA and GLO datasets were placed into 5.08 centimeters classes. Trees that were less than 12.7 centimeters were not available for the FIA data used in this study. For this reason trees of this diameter or smaller were also thrown out for diameter distribution and species composition comparisons. Only 1.2% of GLO trees were less than 12.7 centimeters in diameter.

The GLO data contained 25,196 trees in 63 different taxonomic groups. Some of these groupings were the same actual species. For example, the common name 'red oak' and 'Spanish oak' are probably the same species. The GLO database for the sub-basin included 25,196. The FIA data included 1,720 individual trees from 50 species groups taken from FIA plots.

This study found that changes have taken place in the Buffalo River Sub-basin since pre-Euroamerican times. Species composition appears to have changed dramatically. For instance the white oak group comprised 43% of the GLO witness trees and was only 30.1% of the FIA trees measured in 1999 (Table 1). The red oak group also decreased from 29.8% of the total trees prior to settlement to 18.7% in 1999.

Table 1. Species composition as percent of total trees measured.

Species	GLO[1]	FIA[1]
Ash	1.4	2.4
Basswood	0.3	0.3
Beech	0.9	0.8
Blackgum	4.5	3.4
Cedar	0.7	7.8
Dogwood	0.8	0.8
Elm	2.6	2.8
Maple	1.3	4.1
Pea/Pulse Family	0.3	0.7
Pine	4.1	7.8
Red Oak Group	29.8	18.7
Rose Family	0.3	0.7
Sassafras	0.3	0.8
Sweetgum	0.8	3.1
Sycamore	0.4	0.3
Walnut/Hickory	8.2	14.3
White Oak Group	43.0	30.1

[1]Only includes trees that were greater than 12.7 centimeters.

Not all groups declined. Cedar comprised a mere 0.7% of the total prior to settlement, but was 7.8% of all trees in 1999. Maple increased from 1.3% prior to settlement to 4.1% in 1999 and sweetgum increased from 0.8% to 3.1% at the present. Walnut/hickory increased from 8.2% prior to settlement to 14.3% in 1999. Pine increased from 4.1% prior to settlement to 7.8% in 1999.

Topographic Locations of Species Comparisons

Another factor that changed in certain cases was topographic locations of trees. One of the more notable changes was pine, which was generally found on southwest facing slopes with a mean of 195° prior to settlement, but was found on more southeasterly slopes in 1999 with a mean of 127° (Table 2). Mean aspect for the white oak group was close to due south at 176° prior to settlement, but was more southwesterly in 1999 at 195°. Walnut/hickory changed from a mean southeastern slope of 173° to a mean of almost due south at 180°. Sweetgum changed from a mean aspect of 165° to a mean of 172° while maple changed from 182° to 188°. Cedar also changed with a mean aspect of 192° prior to settlement and a mean of 176°. Ash, dogwood and the red oak group, however displayed very little change. The only species that had a statistically significant change in aspect between the two time periods was pine.

Pine, ash, cedar, red oak and white oak displayed significant changes in location as far as slope is concerned (Table 3). Pine was found to be on a relatively gentler slope in 1999 compared to pre-Euroamerican with a mean slope of 12° (21.3%) in the 1800's and a mean slope of 6° (10.5%) at the present. Ash increased in slope with a mean slope of 12° (21.3%) prior to settlement and a mean slope of 18° (32.5%) in 1999. Cedar experienced a less dramatic decrease in slope with a mean of 16° (28.7%) prior to settlement and a mean of 12° (21.3%) in 1999. The white oak group displayed the smallest significant change from 11° (20.0%) prior to settlement to 12° (21.3%) in 1999. Walnut\hickory, maple and sweetgum did not show significant change in mean slope between the pre-Euroamerican period and the present.

Pine displayed the greatest change in elevation between the two time periods with more than a 100 meter increase (Table 4). Pre-Euroamerican pine was found at an average elevation of 324 meters versus 436 meters in 1999. Dogwood decreased significantly in elevation from 438 meters in the GLO survey to 361 meters in the current survey. Finally, sweetgum decreased in elevation from a mean of 336 meters to 281 meters.

Table 2. Mean aspect by species group.

Species	GLO Aspect (degrees)	GLO Confidence Interval[1]	FIA Aspect (degrees)	FIA Confidence Interval[1]	Paired T-tests[2]
Ash	168	±12.0	169	±30.2	No Change
Blackgum	171	±6.48	165	±25.1	No Change
Cedar	192	±13.8	176	±17.9	No Change
Dogwood	159	±15.1	163	±49.9	No Change
Maple	182	±12.6	188	±20.8	No Change
Pine	195	±6.0	127	±15.2	Change
Red Oak	179	±2.4	179	±10.4	No Change
Sweetgum	165	±14.4	172	±24.3	No Change
Walnut/Hickory	173	±4.8	180	±12.6	No Change
White Oak	176	±2.1	195	±8.0	No Change

[1]Based on 95% C.I. [2]An alpha value of 0.05 was used for all data analysis.

Table 3. Mean slope by species group.

Species	GLO Slope (degrees)	GLO Confidence Interval[1]	FIA Slope (degrees)	FIA Confidence Interval[1]	Paired T-tests[2]
Ash	12	±0.9	18	±2.4	Change
Blackgum	12	±0.4	14	±1.8	No Change
Cedar	16	±1.4	12	±1.0	Change
Dogwood	12	±0.9	9	±2.9	No Change
Maple	13	±0.9	14	±1.5	No Change
Pine	12	±0.4	6	±0.6	Change
Red Oak	10	±0.2	13	±0.8	Change
Sweetgum	11	±1.1	9	±1.3	No Change
Walnut/Hickory	12	±0.3	12	±0.9	No Change
White Oak	11	±0.1	12	±0.6	Change

[1]Based on 95% C.I. [2]An alpha value of 0.05 was used for all data analysis.

Table 4. Mean elevation by species group.

Species	GLO Elevation (meters)	GLO Confidence Interval[1]	FIA Elevation (Meters)	FIA Confidence Interval[1]	Paired T-tests[2]
Ash	335	±12.8	337	±32.3	No Change
Blackgum	432	±8.3	488	±31.6	Change
Cedar	270	±14.1	272	±16.6	No Change
Dogwood	438	±17.8	361	±56.7	Change
Maple	427	±17.0	439	±29.9	No Change
Pine	324	±6.1	436	±24.6	Change
Red Oak	398	±3.2	412	±14.7	No Change
Sweetgum	336	±15.0	281	±29.3	Change
Walnut/Hickory	412	±6.0	421	±15.4	No Change
White Oak	421	±2.9	413	±11.2	No Change

[1]Based on 95% C.I.
[2]An alpha value of 0.05 was used for all data analysis.

Diameter Distributions Comparisons

There were differences in diameter distributions between the surveys (Table 5). Avoidance of smaller diameter trees in the GLO surveys was evident by the large discrepancy in percent composition for the 12.7 to 17.8 centimeter diameter classes. It is interesting to note that oak species make up large percentages of each diameter class in the GLO survey including smaller diameter classes.

Table 5. Diameter distribution of trees in percent.

Diameter (cm)	GLO[1]	FIA[1]
<12.7[3]	1.2	NA[2]
12.7 to 17.8[3]	6.7	46.5
20.3 to 25.4[3]	21.8	28.7
27.9 to 33.0[3]	21.0	13.5
35.6 to 40.6[3]	20.7	5.9
43.2 to 48.3[3]	10.0	3.0
50.8 to 55.9[3]	7.2	1.7
58.4 to 63.5[3]	6.1	0.5
66.0+[3]	5.3	0.2

[1]Numbers represent percentage of the total for each survey respectively.
[2]Trees smaller then 12.7 cm were not included in FIA surveys.
[3]Diameters were originally taken in inches as non-decimal values. This is why there are gaps between centimeter groupings.

Table 6 and 7 shows the diameter distributions for 17 species groups. Cedar increased from 1.1% of all trees between 12.7 to 17.8 centimeters prior settlement, but was 10.6% for the same class in 1999. Pine also increased in the 12.7 to 17.8 centimeter class from 1.8% prior to settlement to 5.8% in 1999. Pine increased in importance quite substantially for all diameter classes between 20.3 and 40.6 centimeters from pre-Euroamerican to 1999. Pine also made up larger percentages of the larger diameter groups prior to settlement than at the present time. Red oak made up a larger percentage of the total for the small diameter classes prior to settlement than in 1999. However red oak appeared to make greater contributions to the mid to larger diameter classes in 1999.

Discussion

Although oak species have maintained their position as the most common species (consisting of 48.8% of the total in 1999 versus 72.7% prior to settlement), there have been dramatic drops since the early 1800's. The white oak group has fallen from 42.7% in the GLO surveys to 30.1% in 1999. The red oak group has followed suit with 29.7% in the GLO surveys and 18.7% in 1999. Factors thought to contribute to this trend include fire suppression, insect outbreaks, and various land management practices that favor other tree species (Abrams 1998).

Recent declines in red oak may be attributed to the red oak borer (*Enaphalodes rufulus*) (Heitzman 2003). In 1999 the US Forest Service estimated that severe damage (greater than 75% mortality) existed on 7,800 hectares of the Ozark National Forest, with an additional 9,800 hectares experiencing moderate damage (50-75% mortality) (Smith and Stephen 2001). One of the main contributors to the red oak borer epidemic was years of drought in the late 1990's, which weakened oak populations (Smith and Stephen 2001). It is also possible that land cultivation and harvesting in the Ozarks led to the decline of larger diameter oaks. For instance, Tucker (1990) stated that oaks were preferred for use as railroad ties and that many were harvested for this purpose in the late 1800's.

The movement of shortleaf pine from more xeric, steep southwest facing slopes to gentler, more southeast facing slopes may be due to fire suppression, which may have allowed less fire-resistant species to

Table 6. General land office (GLO) individual diameter distribution in percent.

Species	12.7 to 17.8[2] (cm)	20.3 to 25.4[2] (cm)	27.9 to 33.0[2] (cm)	35.6 to 40.6[2] (cm)	43.2 to 48.3[2] (cm)	50.8 to 55.9[2] (cm)	58.4 to 63.5[2] (cm)	66.0+[2] (cm)
Ash	1.0	1.5	1.5	1.5	1.0	1.3	1.5	0.9
Basswood	0.2	0.3	0.3	0.3	0.2	0.3	0.4	0.0
Beech	0.7	1.2	1.2	1.2	0.6	0.7	0.2	0.2
Blackgum	6.0	6.7	5.9	3.7	2.9	2.1	1.1	0.7
Cedar	1.1	1.3	1.1	0.4	0.2	0.1	0.1	0.0
Dogwood	7.2	1.4	0.0	0.0	0.0	0.1	0.0	0.0
Elm	5.7	4.2	2.7	1.8	1.1	1.0	0.8	0.8
Maple	4.2	2.4	1.3	0.6	0.2	0.4	0.3	0.1
Pea/Pulse Family	0.8	0.6	0.3	0.3	0.0	0.1	0.0	0.0
Pine	1.8	3.5	3.6	3.8	4.5	4.9	7.2	7.8
Red Oak Group	32.5	31.7	30.6	29.3	28.9	27.5	26.7	24.8
Rose Family	0.7	0.6	0.3	0.2	0.1	0.2	0.0	0.0
Sassafras	1.0	0.9	0.2	0.1	0.0	0.0	0.0	0.0
Sweetgum	0.5	0.6	0.7	0.9	0.8	0.7	0.9	1.4
Sycamore	0.5	0.4	0.4	0.3	0.2	0.2	0.3	1.3
Walnut/ hickory	13.6	12.8	10.2	6.8	4.3	3.0	2.7	1.5
White Oak Group	20.5	29.1	39.5	48.7	55.0	57.4	57.9	60.5

[1]Numbers represent percentage of the total for each diameter class.
[2]Diameters were originally taken in inches as non-decimal values. This is why there are gaps between centimeter groupings.

Table 7. Forest Inventory and Analysis (FIA) individual diameter distribution in percent.

Species	12.7 to 17.8[2] (cm)	20.3 to 25.4[2] (cm)	27.9 to 33.0[2] (cm)	35.6 to 40.6[2] (cm)	43.2 to 48.3[2] (cm)	50.8 to 55.9[2] (cm)	58.4 to 63.5[2] (cm)	66.0+[2] (cm)
Ash	2.8	2.6	1.3	2.0	1.9	0.0	0.0	0.0
Basswood	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Beech	0.9	0.2	0.0	0.0	0.0	6.7	33.3	0.0
Blackgum	3.3	2.2	3.4	6.9	5.8	3.3	22.2	0.0
Cedar	10.6	8.7	2.6	1.0	0.0	0.0	0.0	0.0
Dogwood	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Elm	3.9	2.4	2.2	0.0	0.0	0.0	0.0	0.0
Maple	6.1	2.4	3.9	0.0	0.0	3.3	0.0	0.0
Pea/Pulse Family	1.1	0.2	0.9	0.0	0.0	0.0	0.0	0.0
Pine	5.8	9.9	11.2	10.9	0.0	10.0	0.0	0.0
Red Oak Group	11.3	17.1	30.6	32.7	50.0	43.3	22.2	75.0
Rose Family	0.6	1.2	0.0	0.0	1.9	0.0	0.0	0.0
Sassafras	1.1	0.8	0.4	0.0	0.0	0.0	0.0	0.0
Sweetgum	3.0	3.9	3.4	2.0	0.0	0.0	0.0	25.0
Sycamore	0.1	0.4	0.0	2.0	0.0	0.0	0.0	0.0
Walnut/ hickory	18.0	13.0	9.9	8.9	11.5	0	0.0	0.0
White Oak Group	27.8	34.1	29.3	32.7	28.8	33.3	22.2	0.0

[1]Numbers represent percentage of the total for each diameter class.
[2]Diameters were originally taken in inches as non-decimal values. This is why there are gaps between centimeter groupings.

compete in these areas. It seems logical that in the absence of fire, competitive species might have an advantage in these areas and perhaps reduce recruitment of the shade-intolerant shortleaf pine (Kreiter 1995). It is also possible that shortleaf pine has been planted on gentler slopes, or may have seeded in abandoned fields

Increases in maple from pre-Euroamerican times to the present are also of interest. Red maple is very sensitive to fire (Abrams 1998), which may explain

why maple comprised 1.3% of all witness trees prior to settlement in the Buffalo Sub-basin, versus 4.1% in 1999. Maple increases due to fire suppression in areas once dominated by oaks have been well documented in other studies (Nelson 1997, Mikan et al. 1994, Shotola et al. 1992, Abrams 1998).

Another dramatic change displayed in the Buffalo River Sub-basin is the increase in eastern redcedar. Prior to settlement redcedar accounted for a mere 0.7% of the trees in the sub-basin, compared to the 7.8% observed in 1999. Part of this increase may have been due to surveyor bias against redcedar due to their generally small size and branchiness. However, it is difficult to prove or disprove bias against cedar. The number of cedar trees that were used as corner trees was so small that looking at average distance to determine bias against cedar was impossible. Redcedar trees represent approximately 1% of each diameter class from 12.7 to 33.0 centimeters and then decrease in the GLO surveys. If cedar was more predominant (especially in its average diameter classes) one would expect a larger percentage in these average diameter classes in the FIA data, which had an average diameter of 17.8 centimeters with a standard deviation of 5.1 centimeters. It was not surprising to see approximately 10% of all trees in the 12.7 to 17.8 centimeter diameter class are cedar. Other studies in the region have found significant increases in cedar, especially in glades and abandoned farmland (Schroeder 1981, USDA 1999b). It is important to note that between 1910 and 1940 much of the settled and cleared land was abandoned (especially during the great depression of the 1930's) and was subsequently sold to timber companies and the US Forest Service (USDA 1999b), undoubtedly creating conditions for cedar establishment. The average redcedar tree in 1999 (approximately 18 centimeters), would be the approximate diameter for a cedar tree that was initiated in the 1930's and 1940's. Cedar is also very sensitive to fire and has been found to decrease in abundance under a prescribed fire regime, which may explain its absence in the GLO surveys (Beilmann and Brenner 1951, Lawson 1990, Nelson 1997).

Based on this study it seems likely that many areas that were once predominantly two species groups (red and white oaks) have now become more mixed with less dominance of any one particular species (Table 1). This is not surprising considering the region's fire history, which in the past would have prevented increases in species such as hickory, cedar and maple that have been observed in the Buffalo River Sub-basin over the last couple of centuries (Strausberg and Hough 1997, Abrams 1998).

Additionally, a substantial portion of the sub-basin is now in pasture or other agriculture land (USGS 1998). This factor, combined with increased competition from other tree species due to fire suppression and European settlement, would appear to contribute to the decrease of oak species in the sub-basin and the increase of other species.

Conclusion

Information on biodiversity of landscapes is available for many areas in the 20th Century, but prior to this period little is known over large areas. The GLO survey notes provide us with the only systematic on-ground survey from 1815 to 1850 in Arkansas and they predate most formal botanical investigations, even though the GLO trees are not a statistically representation of the trees of that time period. Portions of the Buffalo River sub-basin could be restored through policies that allows for mimicking pre-Euroamerican conditions. However, modern-day ownership patterns make full restoration of pre-Euroamerican impossible. There is value in understanding the environmental history of an area, and we advise that any natural resource management conducted in the Buffalo River Sub-basin should take into account the historic vegetation patterns. This research gives us some insight into the changes that have occurred in the last 150+ years, which is important for understanding the ecology of the present landscape.

Acknowledgments

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Land-Use/Land-Cover Characterization Using an Object-Based Classifier for the Buffalo River Sub-Basin in North-Central Arkansas

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Abstract

Sensors for remote sensing have improved enormously over the past few years and now deliver high resolution multispectral data on an operational basis. Most Land-use/Land-cover (LULC) classifications of high spatial resolution imagery, however, still rely on basic image processing concepts (i.e., image classification using single pixel-based classifiers) developed in the 1970s. This study developed the methodology using an object-based classifier to characterize the LULC for the Buffalo River sub-basin and surrounding areas with a 0.81-hectare (2-acre) minimum mapping unit (MMU). Base imagery for the 11-county classification was orthorectified color-infrared aerial photographs taken from 2000 to 2002 with a one-meter spatial resolution. The object-based classification was conducted using Feature Analyst®, Imagine®, and ArcGIS® software. Feature Analyst® employs hierarchical machine-learning techniques to extract the feature class information from the imagery using both spectral and inherent spatial relationships of objects. The methodology developed for the 7-class classification involved both automated and manual interpretation of objects. The overall accuracy of this LULC classification method, which identified more than 146,000 features, was 87.8% for the Buffalo River sub-basin and surrounding areas.

Introduction

Land-use/Land-cover is a distinct concept applied to the classification of the earth's land surface (Estes et al. 1982). Land-cover is defined as visible features on the landscape and land-use is defined as human activity on the landscape. For our classification of the Buffalo River sub-basin, we did not distinguish between land-use and land-cover because of the difficulty of identifying land-use of the landscape.

Numerous uses exist for digital LULC classification maps. For example, LULC classification maps provide insight into a region's soils and geology (Ustin et al. 1999, Gupta 2003). Land-use/Land-cover classification maps are used extensively in conservation planning (Turner et al. 2003, Kerr 2003), informing land development decisions in metropolitan areas (Ridd 1995, Weber and Puissant 2003), planning and implementing large-scale inventories of natural resources (Anderson 1982, Volgelmann et al. 1998), and monitoring change in ecosystem/landscape condition over time (Frohn 1998, Lambin 1996, Weng 2002). Land-use/Land-Cover data, particularly when used in conjunction with other data such as terrain maps available from Digital Elevation Models (DEMs), can be useful in identifying areas more or less suited to specific land management practices and thereby aid in the assessment of appropriate practices for use in a specific area to attain certain goals (Bonner et al. 1982).

Traditional methods of mapping vegetation for use in natural resource management/research and conservation planning consist of field surveying and manual mapping using aerial photography or medium to coarse resolution satellite imagery. These techniques, however, do not typically provide the level of resolution and spatial scales required by many natural resource applications. Many wildlife management and research applications, including resource selection modeling, require fine resolution data (<10 m) at large spatial scales (>10,000 ha). Until recently, such data were unavailable or impractical to obtain using field-based techniques and medium to coarse resolution satellite imagery.

Remotely sensed imagery, i.e., satellite and aerial photography, has become a cost efficient, accurate, and precise tool for developing LULC classifications (McRoberts and Tomppo 2007). This study summarizes a novel approach, using an object-based classifier instead of a pixel based classifier, to develop a highly delineated LULC classification map of the Buffalo River sub-basin in North-central Arkansas.

Materials and Methods

Our study area was located in the Ozark Plateau province (Boston Mountains; Bailey 1995) and included the entire Buffalo River sub-basin and surrounding area (Figure 1). The study area consisted

of 788,474 ha and included most of Newton and Searcy counties as well as portions of Baxter, Boone, Carroll, Johnston, Madison, Marion, Pope, Stone, and Van Buren counties. Of the total area, 38,447 ha (4.9%) were managed by the National Park Service under the National Scenic Rivers Act of 1972.

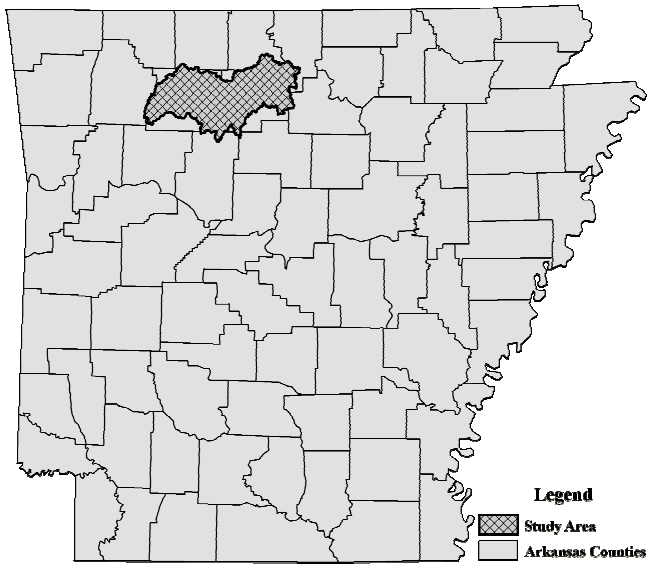

Figure 1. Location of the Buffalo River sub-basin and study area in north-central Arkansas.

The Boston Mountains are erosional remnants of a plateau that were dissected into rough terrain characterized by steep-slopes with flat ridge tops. Elevations range from 240 to 610 m. Our study area was predominately forested, consisting of oak (*Quercus spp.*), hickory (*Carya spp.),* and other hardwoods. Pine (*Pinus spp.)* and cedar (*Juniperus virginiana*) also occurred on selected sites (Bailey 1995). The area is important both ecologically and economically as it contains the states only elk herd. We developed our LULC classification as part of our research into the space use ecology of male elk (White et al. 2005).

The imagery used for the LULC classification was color Infrared (CIR) imagery. The CIR digital orthophoto quadrangle (DOQ) images used in the classification were acquired between May 2000 and January 2002, with most of the images acquired in late January and February 2001. The DOQ images had a pixel resolution of one meter. These images, acquired by the state of Arkansas, were obtained from the Natural State Digital Database (NSDD) (http://sal.uamont.edu) maintained by the Spatial Analysis Laboratory (SAL) at the University of Arkansas at Monticello (UAM).

Pixel-based image classification includes supervised and unsupervised methods (Enderle and Weih 2005). Supervised methods involve classification of pixels of unknown identity by means of a classification algorithm using spectral characteristics of pixels of known identity. Unsupervised methods involve the separation of image pixels into natural groupings based upon similar spectral characteristics by means of a classification algorithm and assignment of groupings into classes.

Marceau et al. (1990) and Hsieh et al. (2001) found that increasing spatial resolution does not necessarily increase classification accuracies because single pixels fail to capture the entire spectral signature of the object being classified. To circumvent this problem, we analyzed not only the individual pixel being classified but also neighboring pixels, resulting in the analysis of both the spectral and spatial structure of objects. Figure 2 illustrates the essential difference between pixel-based and object-based classifiers.

While the idea of using object-based classification to replace pixel-based methods has existed since the early 1970's, the first practical object-based classification model was not developed until 1984 when the Machineseg program was developed. Machineseg was an image-analysis technique that used object shapes, sizes, and spectral signatures obtained from aerial photographs (Flanders et al. 2003). Then in the late 1980's, a "road finder" program was developed that used a segmentation process to identify linear features such as roads, rivers, and field boundaries (Flanders et al. 2003). These early object-based classification models had difficulty combining information from multi-level analyses, validating classifications, reconciling conflicting results, attaining reasonable processing time, and automating analyses (Flanders et al. 2003). Pixel-based methods, which did not suffer from these problems, provided reasonably accurate classifications, and therefore maintained their position as the industry standard (Flanders et al. 2003).

While a fully automated object-based classification process was highly desired, early efforts to develop such models failed due to limitations in hardware, software, image quality (poor resolution), and interpretation theories (Flanders et al. 2003). By the mid-1990's, however, these limitations were being resolved by the development of computers with large memory capacities, fast processing speeds, and the availability of images from high spatial resolution satellite sensors with increased spectral variability (Flanders et al. 2003). Advances in image-segmentation algorithms and intelligent machine - learning algorithms have led to "off-the-shelf" software packages such as Feature Analyst® and

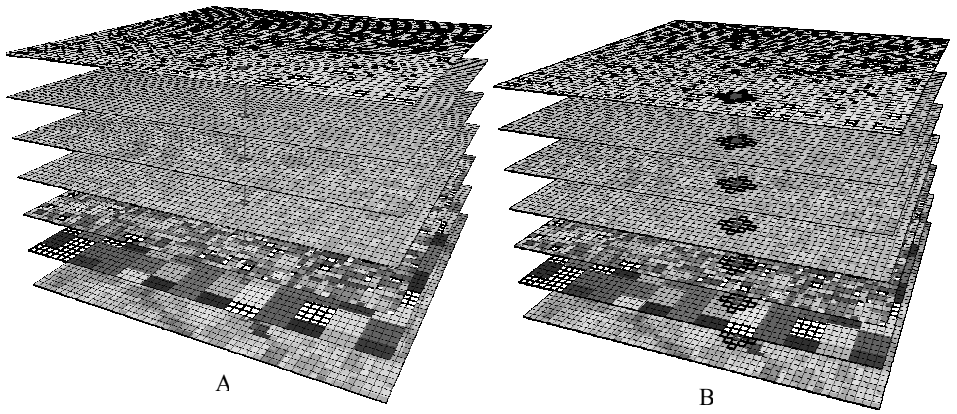

Figure 2. Pixel-based classifiers (A) classify objects within a single pixel using all layers. Object-based classifiers (B) classify objects within a defined region, including the focal pixel (the central-most pixel) using all layers.

eCognition capable of object-based classification methods that equal and often exceed the accuracy of pixel-based classification methods.

Feature Analyst®, which has been designed for use with ArcGIS®, GeoMedia®, SOCET SET®, and ERDAS Imagine® software, is a practical tool for use in LULC classification mapping (Visual Learning Systems 2004a). Feature Analyst® uses a machine-learning algorithm to achieve automated feature extraction (Visual Learning Systems 2004a). Once the software is given user-specified examples (training data sets), it utilizes software agent technology to "learn" to find similar landscape features and appoint a user-defined classification (Visual Learning Systems 2004a). If a series of images of the same area over time are correctly registered to each other, Feature Analyst® can extract changes that may have occurred in the features of the image by creating a change detection raster (Visual Learning Systems 2004b).

O'Brien (2003) at the National Imagery and Mapping Agency (NIMA) compiled a report on a series of tests that compared Feature Analyst® with manual methods currently employed for mapping operations. Feature Analyst® increased production over hand digitization, while at the same time achieved more accurate and consistent results (O'Brien 2003). Results from a questionnaire and discussions with participants of the test indicated a high level of enthusiasm for the Feature Analyst® system. Analysts agreed that the system was easy to learn and easy to use (O'Brien 2003).

The object-based LULC classification workflow used in our study involved 8 steps (Figure 3). The first step was to develop a training data set for the 7 LULC classifications of interest. The study area was divided into 17 approximately equal-area tiles to organize and facilitate the processing of such a large image data set. We developed more than 25 training polygons for each tile for each of our 7 LULC classes (hardwoods, agriculture, conifers, roads, rivers, water (other than river), and urban.

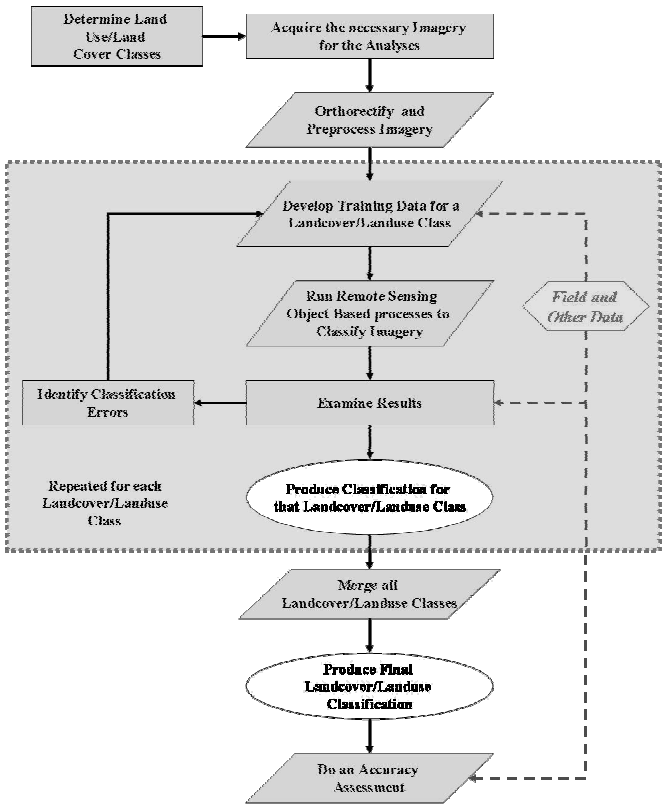

Figure 3. Workflow for developing the Land-use/Land-cover Map Layer using an object based classifier.

Step 2 was to determine the spatial context of neighbors for each LULC class being extracted.

Figure 4 shows an example of the geometric pattern of pixels used to define neighboring pixels that were used to classify a focal (or central) pixel. The geometric pattern of pixels was different for each of the classes. The characteristics of a LULC class can be better represented by an organized group of pixels (spatial feature representation) than single pixels as used in traditional pixel based classifiers for high spatial resolution images. In this step we ran the object-based classifier (Feature Analyst®) and visually examined the results.

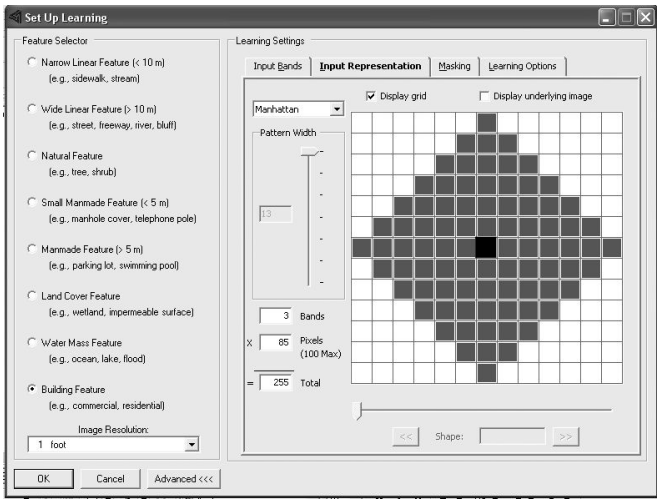

Figure 4. Spatial pattern of an object-based classifier used to classify a single pixel (black square).

Third, we examined the results and identified the features correctly and incorrectly classified. This is a function of Feature Analyst® to assist it in the learning process to classify a feature class. The MMU for the classification was 0.81 ha (2-acres) except for water (other than river), which was 0.04 ha (0.1 acre). The MMU determines the minimum size any feature must be to be considered a separate feature.

Fourth, we repeated steps 1 and 2 with correct and incorrect classified features. In the fifth step, the process was started over for the next LULC class (Figure 3).

For sixth step of the process, after all classes were extracted from the images on each tile, they were merged based on a model that prioritizes the LULC classes. This was done for each of the 17 image tiles in ERDAS Imagine. In the seventh step, we merged all tiles and produced a single LULC classification map for the study area (Figure 5).

In the eighth and last step, we conducted an accuracy assessment of our map by randomly selecting 795 reference data points in the study area (Congalton and Green 1999). The selection of a proper and efficient sample design to collect valid reference data is an important component of any accuracy assessment because the design will determine both the cost and the statistical rigor of the assessment (Congalton and Green 1999). Congalton and Green (1999) list five common sampling schemes for acquiring reference data: simple random sampling, systemic sampling, stratified random sampling, cluster sampling, and stratified systemic unaligned sampling. They recommend stratified random sampling, where a minimum number of samples are selected from each stratum (i.e., map category) (Congalton and Green 1999). This study used this sampling technique in an attempt to collect representative samples from all the LULC classes in the study area. Each reference point was then identified as one of our 7 land-cover classes by an individual not associated with the construction of the classification.

What constitutes an acceptable level of classification accuracy is debatable. Foody (2002) recommended an 85% target for user's, producer's, and overall accuracies derived from the error matrix. While this level may exist as a *de facto* standard, accuracy assessments of Geographic Information System (GIS)-produced maps often fail to meet this criterion (Anderson et al. 1976, Foody 2002). This is probably due to the fact that for each component of accuracy there is a set of accuracy measures that may be calculated to express it (Foody 2002). In reality, it is probably impossible to specify a single, all-purpose measure of classification accuracy, because it depends on the application and the level of comfort the practitioner has with the classification.

When evaluating an image classification, there are two forms of accuracy that can be considered. Non-site-specific accuracy (NSSA) considers the overall agreement between the classified image and the reference data without examination of the agreement between them at specific locations. For example, NSSA involves the examination of the percent Mature Pine Forest in the classified image and the comparison of it to the percent Mature Pine Forest in the reference data. Relying solely on non-site-specific accuracy to evaluate a classification can hide errors resulting from disagreement in the placement of classes between the classified image and the reference data.

The second form of accuracy is site-specific accuracy (SSA), which examines the agreement between classes at specific locations on the classified image and in the reference data. This examination is done by means of an error matrix (also known as a confusion matrix or contingency table) to compare, for specific locations, what LULC class is the reference

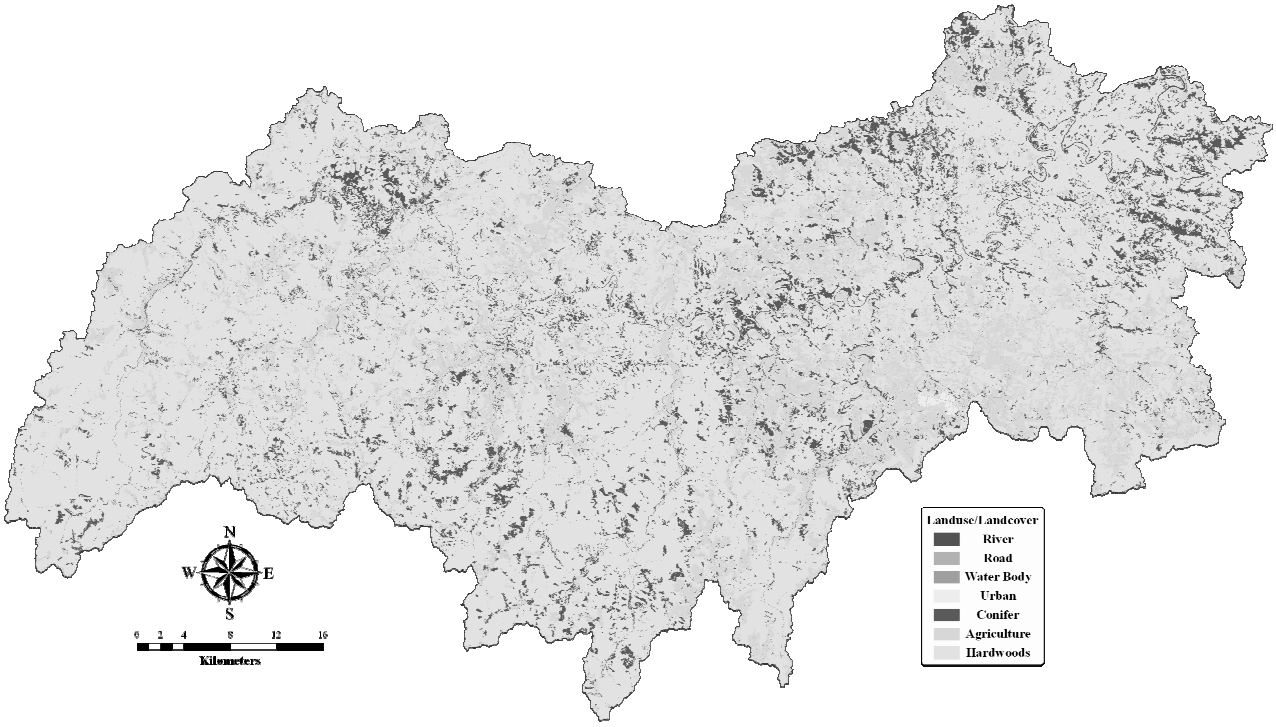

Figure 5. Buffalo River sub-basin Land-use/Land-cover classification.

data versus how that area was classified. The error matrix helps to identify instances of classification error for specific classes

There are two types of classification errors: errors of omission and errors of commission. Errors of omission are instances in which site has been excluded from a class to which it actually belongs. Errors of commission are instances in which a site is included in an incorrect class. Campbell (2007) noted that these errors tend to balance each other, as an error of omission for one class will also be tabulated in the error matrix as an error of commission in another class. Given the characteristics of these errors, it is best to examine them on a class-by-class basis before assuming the errors in one class reflect the errors found in all classes.

For SSA assessment using the error matrix, there are three primary measures of classification accuracy: overall classification accuracy, producer's accuracy, and user's accuracy. Overall classification accuracy is a measure of how much area was correctly classified for the entire area classified. From the error matrix, overall classification accuracy is the sum of the diagonals divided by the total.

Producer's accuracy is calculated for each class and provides an indication of how well a particular class has been classified by the producer of that classification. This accuracy is most often used by the producer as a means to assess how well the classifier performed. From the error matrix, the producer's accuracy for each class is the result of dividing the correctly classified pixels by the number of reference data pixels in that class.

User's accuracy is also calculated for each class and provides an indication of how often the areas assigned to a given class on the image classification actually belong to that class on the landscape. This accuracy is of greater importance to the users of the classification because this indicates how true the classified image is to the actual situation on the ground. From the error matrix, the user's accuracy for each class is the result of dividing correctly classified pixels in a given class by the total number of pixels in that class for the classified image. We report all three primary measures of classification accuracy in this study.

The area of each class in the study area was clipped using the watershed boundary of the Buffalo River in a GIS. The Buffalo River sub-basin boundary was calculated using a 5-m DEM in a GIS.

Results and Discussion

Number of features classified, area, and percentage of study area for each classification in the study area is summarized in Table 1. Almost 82% of the study area (282,967.10 ha) was forested. The two most common land-cover types in the study area were hardwoods (73.43%) and agriculture (16.49%). More than 6,000

Table 1. Number of features classified, area, and percentage of total study area by Land-use/Land-cover type.

Land Cover	Number of Features	Acres	Hectares	Percentage
Agriculture	21,243	141,068.0	57,072.9	16.49%
Roads	430	9,063.5	3,667.7	1.06%
Conifer	28,863	71,183.5	28,770.8	8.31%
Hardwoods	88,748	628,615.8	254,196.3	73.43%
Rivers	724	4,247.2	1,717.9	0.50%
Urban	149	873.7	353.2	0.10%
Water (non-river)	6,463	1,129.4	404.3	0.12%
Total	146,620	856,181.1	346,183.1	

water structures (mostly ponds) were identified and 1.06% of the study area was covered by roads.

Although classification accuracy varied by LULC type, the overall accuracy of our map was 87.8% (Table 2), which is the percentage of correct ground reference points for the LULC map. Producer and user accuracies varied from 46.6% to 100% and 79% to 100%, respectively (Table 2). Water (other than river) was accurately classified 100% of the time by both producers and users and linear features, such as rivers and roads, were correctly classified >97% of the time by both producers and users.

Table 2. Producer's and user's accuracy by Land-use/Land-cover type.

Land Cover	Producer's Accuracy	User's Accuracy
Rivers	97.2%	100.0%
Roads	97.0%	98.5%
Water (non-river)	100.0%	100.0%
Urban	48.5%	100.0%
Conifer	46.6%	80.4%
Agriculture	88.3%	79.0%
Hardwood	95.6%	86.6%
Overall Accuracy	87.8%	

As previously stated, producer's accuracy relates to the probability that a reference sample point will be correctly mapped and measures the errors of omission and producer's accuracy indicates the probability that a sample from LULC map actually matches the reference sample data and measures the error of commission. Users of the LULC map are interested in user's accuracy.

Producers misclassified conifers and urban features most frequently, whereas users misclassified agriculture most frequently. Conifers and urban features were correctly classified <46% of the time by producers but correctly classified >80% of the time by users. Although only 2.3% of 432 hardwood reference points were misclassified as conifer, 52.3% of 88 conifer reference points were misclassified as hardwood. This led to the low classification accuracy for conifers by producers (Table 2). It was easier to accurately identify hardwoods than it was conifers in our study area. This is probably explained by the criteria we set to designate an area as conifer (i.e., an area must be >50% conifer to be designated conifer). In our study area, conifers do not typically occur in large, dense stands but occur at relatively low basal areas mixed with hardwoods. Visually estimating percent coverage of a sparely distributed land-cover type is difficult and error prone.

The classifier classified 11.7% of 94 agriculture reference points as hardwood, which lowered the accuracy of this LULC class (Table 2). Typically, an agricultural field in the study area contained hardwoods, which complicated classification efforts for the same reason conifers were difficult to distinguish from hardwoods.

All urban areas in the classified image were classified correctly, 100% User's Accuracy (Table 2), but some urban area field data points were classified as agriculture and hardwood. This is reflected in the 48.5% producer's accuracy.

In summary, Feature Analyst® processes are similar to the way human interpreters identify objects, which involves: association, color, pattern, shadow, shape, size, and texture (Caylor 1998). A pixel based classifier might only look at color (spectral signature) and possibility texture or pattern in an advanced classification process workflow. The methodology developed for this study showed that an object-based classifier can produce accurate LULC classifications with high spatial resolutions.

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Improvement of Prony's Method of System Identification via Nonlinear Parameter Transformation

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Abstract

This paper presents an approach to improve Prony's method of identifying a linear time-invariant system. The method is based on a nonlinear transformation of parameters, which leads to data averaging. The method yields better results than a direct application of the least squares approach to Prony's method. A numerical example is given to demonstrate the improvement attained by the new algorithm. Signals are assumed to be contaminated by zero-mean Gaussian white noise.

Introduction

In the past few decades, numerous research activities have been devoted to the identification of linear time-invariant systems (Åström et al. 1971) Among some well-known approaches are Prony-based methods (Lacroix 1973, Khatwani et al. 1975, Kumaresan 1990, Pierre et al. 1992, Hietpas 1994, Pierre et al. 1995), Mellin deconvolution (Prost et al. 1976) numerical computation of Laplace transform (Unnikrishnan 1980) and genetic algorithm (Kristinsson et al. 1992). For control applications, it is often required to determine a system transfer function with certain accuracy from a limited amount of sampled data (Kumaresan 1990 and Pierre 1995).

This paper presents an improvement of Prony's method of transfer function identification. An algorithm is developed based on the introduction of finite differences. The result is a nonlinear transformation of the parameters to be identified. A numerical study of an example extracted from the literature (Lacroix 1973) is presented. The different cases of varying sampling intervals are considered. Results with recursive implementation are compared with those of the conventional Prony method.

Materials and Methods

Prony's Method

Consider a linear time-invariant system in Figure 1

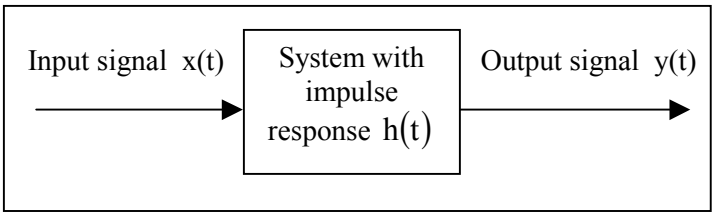

Figure 1. Linear time-invariant system with impulse response h(t).

with the following rational transfer function:

$$H(s) = k\frac{\prod_{j=1}^{m}(s - z_j)}{\prod_{i=1}^{n}(s - p_i)} \tag{1}$$

where m < n, and the poles p_i are assumed to be distinct. On taking partial fraction expansion, H(s) in Eq. (1) becomes

$$H(s) = \sum_{i=1}^{n}\frac{c_i}{s - p_i} \tag{2}$$

Inverse Laplace transform of Eq. (2) gives the impulse response of the system as a sum of exponential terms:

$$h(t) = \sum_{i=1}^{n} c_i e^{p_i t} \tag{3}$$

The objective of the following is to identify the unknown exponents p_i and the unknown weights c_i. Let the system impulse response h(t) be sampled with a sampling interval of Δt to yield N data points. Then, with $\phi_i \triangleq e^{p_i \Delta t}$, Eq. (3) gives

$$h(k\Delta t) \triangleq y_k = \sum_{i=1}^{n} c_i \phi_i^k, \quad k = 0, 1, \cdots, N-1 \tag{4}$$

which, written in full, yields the following system of N equations in 2n unknowns:

$$\begin{aligned} c_1 &+ c_2 &+\cdots &+ c_n &= y_0 \\ c_1\phi_1 &+ c_2\phi_2 &+\cdots &+ c_n\phi_n &= y_1 \\ c_1\phi_1^2 &+ c_2\phi_2^2 &+\cdots &+ c_n\phi_n^2 &= y_2 \\ & & \vdots & & \\ c_1\phi_1^{N-1} &+ c_2\phi_2^{N-1} &+\cdots &+ c_n\phi_n^{N-1} &= y_{N-1} \end{aligned} \tag{5}$$

If more samples than necessary are taken to reduce the effect of noise, i.e. N > 2n, the unknown system can be identified by solving the above set of overdetermined nonlinear algebraic equations. From difference equation theory, y_k in Eq. (4) is the general solution of the nth order difference equation:

$$\begin{aligned} y_{k+n} + \tilde{c}_{n-1}y_{k+n-1} + \cdots + \tilde{c}_1 y_{k+1} + \tilde{c}_0 y_k = 0 \\ k = 0, 1, \cdots, N-n-1 \end{aligned} \tag{6}$$

Thus, ϕ_i in Eq. (4) must satisfy the characteristic equation of Eq. (6):

$$\phi^n + \tilde{c}_{n-1}\phi^{n-1} + \cdots + \tilde{c}_1\phi + \tilde{c}_0 = 0 \tag{7}$$

Equation (6) can be expressed in matrix notation as

$$\mathbf{A}\tilde{\mathbf{c}} = -\mathbf{y_1} \tag{8}$$

where

$$\mathbf{A} = \begin{bmatrix} y_0 & y_1 & \cdots & y_{n-1} \\ y_1 & y_2 & \cdots & y_n \\ \vdots & \vdots & & \vdots \\ y_{N-n-1} & y_{N-n} & \cdots & y_{N-2} \end{bmatrix} \tag{9}$$

$$\tilde{\mathbf{c}} = \begin{bmatrix} \tilde{c}_0 \\ \tilde{c}_1 \\ \vdots \\ \tilde{c}_{n-1} \end{bmatrix} \tag{10}$$

$$\mathbf{y_1} = \begin{bmatrix} y_n \\ y_{n+1} \\ \vdots \\ y_{N-1} \end{bmatrix} \tag{11}$$

The coefficient vector $\tilde{\mathbf{c}}$ can be obtained in the least-squares sense by

$$\tilde{\mathbf{c}} = -(\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{y_1} \tag{12}$$

with the assumption that **A** is of full rank.

After $\tilde{\mathbf{c}}$ have been determined, the ϕ_i in Eq. (5) are then calculated as the n roots of Eq. (7). They are either real or appear in complex conjugate pairs. With known ϕ_i, Eq. (5) can be written in the following form

$$\mathbf{\Phi c} = \mathbf{y} \tag{13}$$

where

$$\mathbf{\Phi} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ \phi_1 & \phi_2 & \cdots & \phi_n \\ \vdots & \vdots & & \vdots \\ \phi_1^{N-1} & \phi_2^{N-1} & \cdots & \phi_n^{N-1} \end{bmatrix} \tag{14}$$

$$\mathbf{c} = \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} \tag{15}$$

$$\mathbf{y} = \begin{bmatrix} y_0 \\ y_1 \\ \vdots \\ y_{N-1} \end{bmatrix} \tag{16}$$

Once again, using the least-squares approach, **c** in Eq. (13) can be evaluated. By taking the natural logarithm of $\phi_i = e^{p_i \Delta t}$[1], the system poles p_i can be determined. Therefore, all the n unknown weights and exponents in Equation (3) are completely obtained. The unknown system H(s) in Eq. (2) is hence identified.

Improvement of Prony's Method using Finite Differences

The following is a modification of Prony's algorithm based on the idea that averaging multiple captures of a signal will reduce the effect of noise in the final result. In Eq. (6), y_k are known data values, and the unknown parameters to be estimated are $\tilde{c}_i$. The basic idea of the proposed method is to re-write Eq. (6) into a different form by introducing finite differences as follows. Consider the sequence y_k, k = 0, 1,⋯, N – 1. Define the finite difference operator Δ as

[1] Here, it is assumed that the sampling interval Δt does not exceed an upper limit of $\Delta t \le \dfrac{\pi}{\max|\mathrm{Im}\, p_i|}$ so that $\ln \phi_i$ will be a single-valued function (see Lacroix 1973).

$$\begin{aligned}\Delta^0 y_k &\triangleq y_k \triangleq y_k^{(0)}\\ \Delta^1 y_k &\triangleq y_k - y_{k-1} \triangleq y_k^{(1)}\\ \Delta^2 y_k = \Delta(\Delta y_k) &= \Delta y_k^{(1)} \triangleq y_k^{(1)} - y_{k-1}^{(1)} \triangleq y_k^{(2)}\\ &\vdots\\ \Delta^n y_k &\triangleq \Delta(\Delta^{n-1} y_k) \triangleq y_k^{(n)}\end{aligned} \tag{17}$$

It can be shown (see Appendix) that Eq. (6) can be re-written in terms of the finite differences defined above as

$$\begin{aligned} b_n y_k^{(n)} + b_{n-1} y_k^{(n-1)} + \cdots + b_1 y_k^{(1)} &= -y_k,\\ k &= n, n+1, \cdots, N-1\end{aligned} \tag{18}$$

Here, the finite differences $y_k^{(1)}, \cdots, y_k^{(n)}$ can be calculated from the data values y_k, and the parameters $b_1, b_2, \cdots, b_n$ are to be estimated. The former parameters $\tilde{c}_0, \tilde{c}_1, \cdots, \tilde{c}_{n-1}$ and the new parameters $b_1, b_2, \cdots, b_n$ are related by

$$\tilde{c}_i = \frac{(-1)^{n-i} \sum_{\nu=n-i}^{n} \binom{\nu}{n-i} b_\nu}{1 + \sum_{\nu=1}^{n} b_\nu}, \quad i = 0, 1, \cdots, n-1 \tag{19}$$

Eq. (19) represents a nonlinear parameter transformation between b_i and $\tilde{c}_i$.

Next, we sum up both sides of Eq. (18) from k = n to an arbitrary value of k to yield

$$\begin{aligned} b_n y_k^{(n-1)} + b_{n-1} y_k^{(n-2)} + \cdots b_1 y_k &= -\sum_{k1=n}^{k} y_{k1}\\ k &= n, n+1, \cdots, N-1\end{aligned} \tag{20}$$

In obtaining Eq. (20), use has been made of the relation

$$\sum_{k_1=n}^{k} y_{k_1}^{(i)} = y_k^{(i-1)}, \quad i = 1, 2, \cdots, n \tag{21}$$

which is valid provided that (straight-forward to verify)

$$y_{n-1}^{(n-1)} = y_{n-1}^{(n-2)} = \cdots = y_{n-1}^{(0)} = 0 \tag{22}$$

Note that assumption (22) is equivalent to "zero initial-conditions", i.e.

$$y_0 = y_1 = y_2 = \cdots = y_{n-1} = 0 \tag{23}$$

Summing up Eq. (20) from k=n to any k yields

$$\begin{aligned} &b_n y_k^{(n-2)} + b_{n-1} y_k^{(n-3)} + \cdots + b_2 y_k + b_1 \sum_{k_2=n}^{k} y_{k_2}\\ &= -\sum_{k_2=n}^{k} \sum_{k_1=n}^{k_2} y_{k_1} \qquad k = n, n+1, \cdots, N-1\end{aligned} \tag{24}$$

A similar summing process is applied to over Eq. (24) to yield the next equation, and this summing process is repeated successively up to a total of n times to give

$$\begin{aligned} &b_n y_k + b_{n-1} \sum_{k_n=n}^{k} y_{k_n} + b_{n-2} \sum_{k_n=n}^{k} \sum_{k_{n-1}=n}^{k_n} y_{k_{n-1}} + \cdots\\ &+ b_1 \sum_{k_n=n}^{k} \sum_{k_{n-1}=n}^{k_n} \cdots \sum_{k_2=n}^{k_3} y_{k_2} = -\sum_{k_n=n}^{k} \sum_{k_{n-1}=n}^{k_n} \cdots \sum_{k_1=n}^{k_2} y_{k_1}\\ &k = n, n+1, \cdots, N-1\end{aligned} \tag{25}$$

Putting Eqs. (20), (24) on up to (25) in reserve order in matrix form, we have

$$\begin{bmatrix} y_k^{(-n+1)} & y_k^{(-n+2)} & \cdots & y_k^{(-1)} & y_k \\ y_k^{(-n+2)} & y_k^{(-n+3)} & \cdots & y_k & y_k^{(1)} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ y_k^{(-1)} & y_k & \cdots & y_k^{(n-3)} & y_k^{(n-2)} \\ y_k & y_k^{(1)} & \cdots & y_k^{(n-2)} & y_k^{(n-1)} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = -\begin{bmatrix} y_k^{(-n)} \\ y_k^{(-n+1)} \\ \vdots \\ y_k^{(-2)} \\ y_k^{(-1)} \end{bmatrix}, \qquad k = n, n+1, \cdots, N-1 \tag{26}$$

where

$$y_k^{(-i)} \triangleq \sum_{k_i=n}^{k} \sum_{k_{i-1}=n}^{k_i} \cdots \sum_{k_1=n}^{k_2} y_{k_1}, \quad i = 1, 2, \cdots, n \tag{27}$$

The unknown parameters b_i can be solved from the symmetric system (26) for any given time $k = n, n+1, \cdots, N-1$ provided that the square matrix is invertible. Using Eq. (19), the original parameters $\tilde{c}_i$ can be calculated. With known $\tilde{c}_i$, the rest of the procedure follows what is described in Section II.

Results

The two methods described in Sections I and II were applied, respectively, to identify a system with the help of MATHCAD software. The system to be identified

is a fifth-order system from (Lacroix A. 1973) with the poles: $p_1 = -1$, $p_{2,3} = -1 \pm jl$, $p_{4,5} = -1 \pm j2$. The unit impulse response for this system is given by

$$h(t) = \frac{5}{2}e^{-t} - \frac{5}{3}e^{(-1+j1)t} - \frac{5}{3}e^{(-1-j1)t} + \frac{5}{12}e^{(-1+j2)t} + \frac{5}{12}e^{(-1-j2)t} \quad (28)$$

The impulse response sampled with 100 points over a period of 6 seconds is shown in Figure 2.

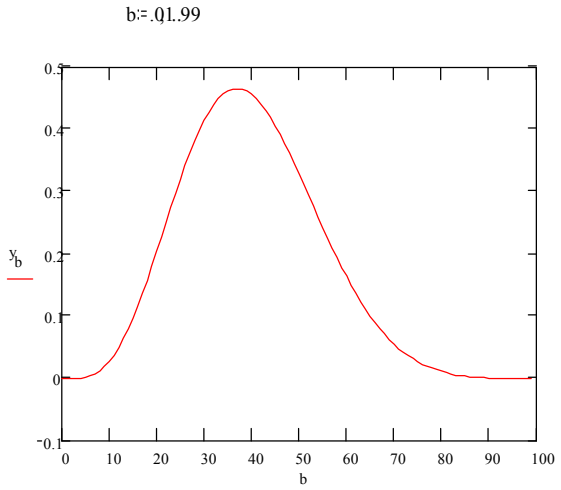

Figure 2. Impulse Response of 5-pole System for 100 Sample Points.

To evaluate the two algorithms, the impulse response is first sampled, and then a Gaussian white noise of zero mean is added onto the sampled data. The standard deviation of the noise added is 3% of the maximum value of the impulse response. Figure 3 shows a typical noise-contaminated impulse response for 100 sample points.

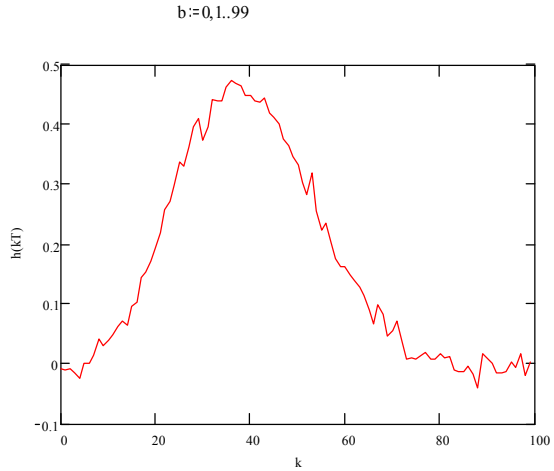

Figure 3. Impulse response of system (28) contaminated with a zero-mean Gaussian white noise 100 sample points.

Table 1 summarizes the identification results of the conventional Prony's method for 40, 70 and 100 sample points, all taken over a period of 6 seconds. Ten randomly generated noise sequences as described above are superimposed in the impulse response h(kΔt). The corresponding sampling intervals are 0.15, 0.0857142 and 0.06 sec, respectively. All the sampling intervals used above comply with the criterion of Footnote 1, because:

$$\frac{\pi}{\max\left|\mathrm{Im}\{p_i\}\right|} = \frac{\pi}{2} = 1.571$$

Table 1. The root-mean-square identification errors for the conventional Prony method when data are contaminated by 10 randomly generated noise sequences

.

Number Trials	of 40 Points	70 Points	100 Points
1st Trial	0.08491	0.08091	0.10630
2nd Trial	0.08145	0.08217	0.11630
3rd Trial	0.08020	0.07869	0.12290
4th Trial	0.06722	0.08521	0.10590
5th Trial	0.06894	0.08244	0.11560
6th Trial	0.07818	0.08553	0.10360
7th Trial	0.07651	0.08070	0.10960
8th Trial	0.07266	0.08194	0.11300
9th Trial	0.07897	0.09079	0.10580
10th Trial	0.07838	0.08047	0.09243
Average	0.07674	0.08289	0.10914

The root-mean-square identification error in Table 1 is defined as

$$e_{rms} \triangleq \sqrt{\frac{\sum_{k=0}^{N-1}\left|\hat{y}_k - y_k\right|^2}{N}} \quad (29)$$

where N is the total number of sample points, and $\hat{y}_k$ is the output of the identified model i.e. the value of y_k as calculated according to Eq. (4) when estimates for c_i and ϕ_i are used.

Table 2 shows the comparison results of the finite-difference method with 40, 70 and 100 points. The same 10 sets of data were used as those in Table 1.

Table 2. The root-mean-square identification errors for the proposed finite-difference method with the same 10 contaminated data sequences as in Table 1.

Number Trials	of 40 Points	70 Points	100 Points
1st Trial	0.05004	0.08147	0.07520
2nd Trial	0.05330	0.07437	0.08194
3rd Trial	0.06184	0.06665	0.07280
4th Trial	0.05652	0.07423	0.08463
5th Trial	0.05831	0.07880	0.07205
6th Trial	0.05121	0.05213	0.08637
7th Trial	0.05445	0.08075	0.08533
8th Trial	0.05599	0.07624	0.07260
9th Trial	0.06825	0.06118	0.08131
10th Trial	0.06184	0.08299	0.07310
Average	0.05718	0.07288	0.07853

As can be seen from the comparing of Tables 1 and 2, the proposed finite-difference method outperforms the conventional Prony's method in terms of accuracy. The reductions in the root-mean-square error for the 40-point, 70-point and 100-point cases are, on the average, 25%, 12% and 31%, respectively.

Table 3. The demonstration of a "two-tailed, paired t-test for the establishment of statistically significant data.

		t	df	Sig. (2-tailed)
Pair 1	T1.40 - T2.40	7.427	9	.000
Pair 2	T1.70 - T2.70	2.564	9	.030
Pair 3	T1.100 - T2.100	8.644	9	.000

Table 3 was simulated using SPSS statistical software to compare the before added noise data and after added noise data. Pair 1 of Row 2 in Table 3 was compared before the added noise and after the added noise for 40 points. Pair 2 of Row 3 in Table 3 was compared before the added noise and after added noise for 70 points. Pair 3 of Row 4 in Table 3 was compared before the added noise and after added noise for 100 points. As can be seen from Column 4 of Table 3, to establish the improvement of statistically significant, the compared data have shown that ($p < 0.05$). In specific, for comparison of p value for 40- point and 100 -point are zero. The comparisons of p value for 70-points is only 0.03. Therefore, all the compared data are statistically significant.

Conclusions

A method is presented to improve the performance of the conventional Prony's approach of transfer function identification. The method is based on the introduction of finite differences, resulting in a nonlinear transformation of the system parameters to be identified. A numerical study was conducted on a five-pole system extracted from the literature. The proposed finite-difference method was found to yield consistently more accurate results than the conventional Prony's approach. The motivation of this research is to impact the controllability of linear time-invariant system.

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Resonance Raman Spectroscopy for the Investigation of Heteroleptic Ruthenium Polypyridine Complexes

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Resonance Raman (RR) spectroscopy is a very powerful tool for the study of the structural and electronic properties of ruthenium (II) complexes with 2,2'-bipyridine and related ligands, in both the ground and ^{3}MLCT (triplet metal-to-ligand charge transfer) excited states. Resonance Raman spectroscopy is especially very useful for the unambiguous assignment of electronic absorption spectra (Manuel et al. 1997, Danzer and Kincaid 1990, Danzer et al. 1993). In conventional Raman spectroscopy we measure the spectrum of the scattered radiation at some angle (90 degree is very common) with a spectrometer. Intensities of the Raman lines are very weak compared to the intensity of the source, as a result their detection and measurement are somewhat challenging. Raman line intensities can be greatly enhanced by measuring the resonance Raman spectrum. In resonance Raman, the sample is irradiated with a laser line that is close in energy to the electronic transition of a particular chromophoric group in a molecule. The intensities of the Raman bands of this chromophore are selectively enhanced by a factor of 10^3 to 10^5 under this condition (Ferraro and Nakamoto 1994). In systems containing two chromophoric groups having different transition energies, RR can thus be used to assign an absorption band to a particular chromophore by selective enhancement of its characteristic vibrational modes.

Raman spectroscopy is useful in probing the vibrational data similar to infrared spectroscopy, which helps us to obtain structural and electronic information. Although Raman spectroscopy and infrared spectroscopy are considered to be complementary, Raman spectroscopy finds greater applicability because of three factors. First, water (often the preferred solvent) does not pose any problem as it does in infrared spectroscopy. Second, glass and quartz cells can be used instead of alkali halide or other atmospherically unstable window materials. Most importantly, Raman spectroscopy provides information about the totally symmetric vibrational modes that play an important role in photophysical processes. Unlike infrared spectroscopy, Raman spectroscopy can easily probe the excited states.

Complexes of ruthenium (II) with 2,2'-bipyridine (bpy) and related ligands have attracted much attention over the past two decades as potentially useful components of solar energy conversion devices (Meyer 1978 and 1989, Juris et al. 1988). We employ the commonly used bridging ligand, 2,3-bis(2-pyridyl)pyrazine (dpp) to prepare the mixed ligands complex, $Ru(bpy)_2(dpp)^{2+}$ (where bpy = 2,2'-bipyridine and dpp = 2,3-bis(2-pyridyl)pyrazine). The structure of the complex is shown in Figure 1.

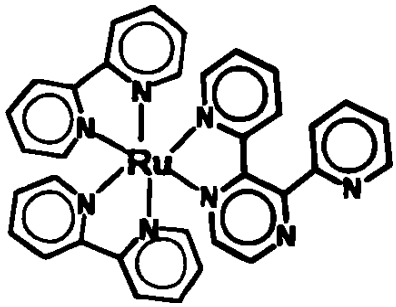
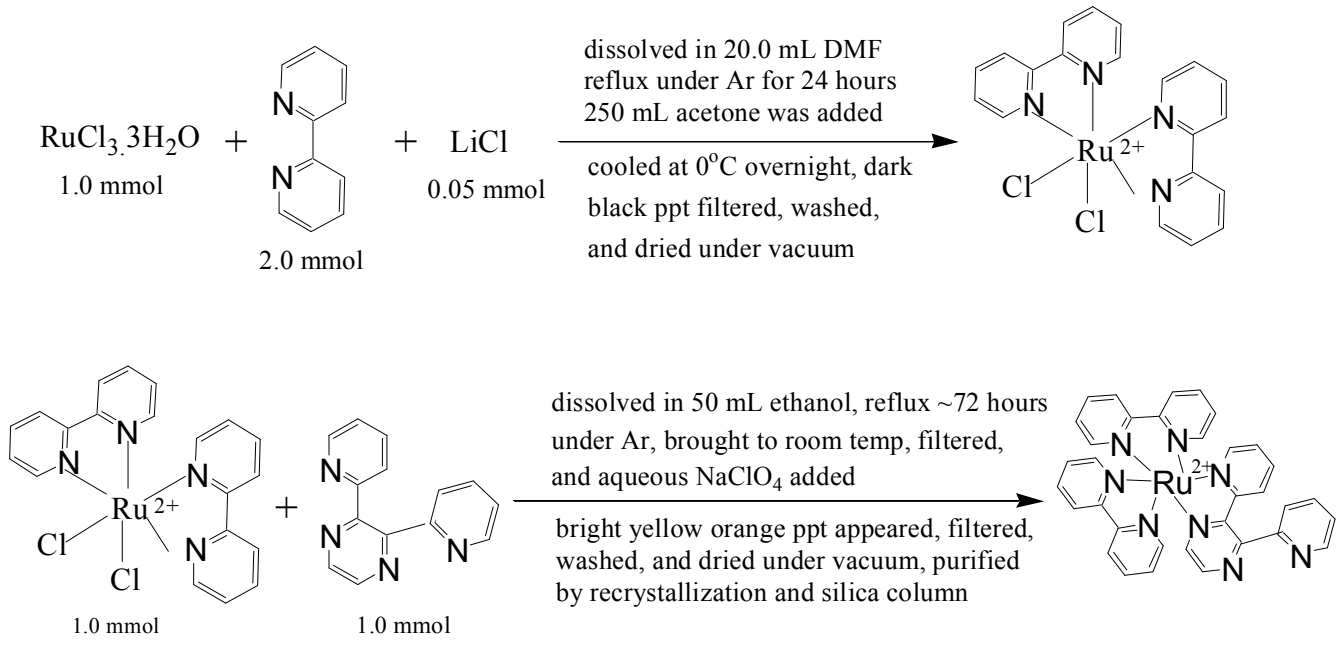


Figure 1. Structure of $Ru(bpy)_2(dpp)^{2+}$ complex (where bpy = 2,2'-bipyridine and dpp = 2,3-bis(2-pyridyl)pyrazine).

The complex $Ru(bpy)_2Cl_2$ was prepared from $RuCl_3.3H_2O$ according to the method described by Sprintschnik et al. (1977) and $Ru(bpy)_2(dpp)ClO_4$ was prepared from $Ru(bpy)_2Cl_2$ and a stoichiometric amount of dpp ligand, according to the previously described method (Braunstein et al., 1984; Bhuiyan and Kincaid, 1999). The sample was purified by repeated recrystallization from 1:1 water ethanol solution and further purified on a silica gel column , which was eluted with a 0.5 M ethanolic solution of $(C_2H_5)_4NBr$. The synthetic procedure is shown in Scheme 1. This study reports the resonance Raman spectra of $Ru(bpy)_2(dpp)^{2+}$. The results permit the definitive assignment of the ground state absorption bands of $Ru(bpy)_2(dpp)^{2+}$ complex.

Electronic absorption spectrum was obtained using a Hewlett-Packard Model 8452A diode array spectrometer using a 1-cm quartz cuvette. Spectrum was obtained in the absorbance mode. The absorption



Scheme 1. Synthetic scheme for the preparation of $Ru(bpy)_2(dpp)^{2+}$ complex.

spectrum of the complex in water solution, shown in Figure 2, matches the absorption spectrum reported by Kalyanasundaram and Nazeeruddin (1990). The absorption spectrum of the complex consists of a series of absorption bands in the uv and visible region. The intense uv bands are ascribable to the ligand centered π-π^* transitions. The visible spectrum is not well resolved and consists of absorption bands at ~424 nm and ~474 nm. The visible bands are assigned to d-π^* MLCT transitions. Resonance Raman spectroscopy can be used for definitive assignment of these visible bands.

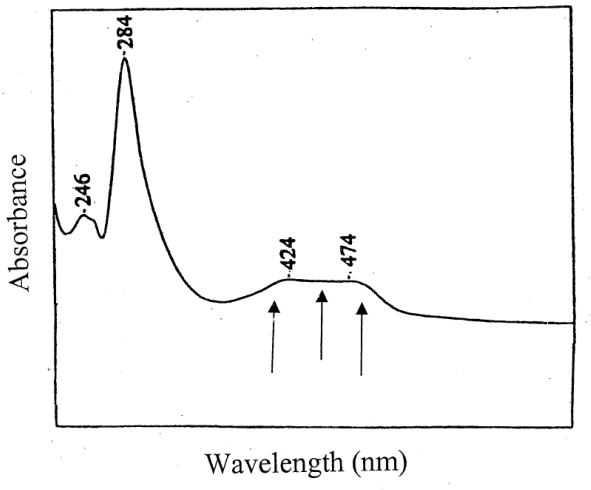


Figure 2. Electronic Absorption spectrum of $Ru(bpy)_2(dpp)^{2+}$ complex. The arrows indicate the excitation wavelengths used in the RR studies.

The resonance Raman spectra of the complex was measured at Marquette University. A block diagram of the instrumentation is shown in Figure 3. The spectra were obtained with a Spex model 1403 double monochromator equipped with a Spex model DM1B controller and Hamamatsu R928 photomultiplier tube. The excitation lines 488.0 and 457.9 nm were obtained from a Spectra-Physics model 2025-05 argon ion laser and the 413.1 nm excitation line was obtained from a Coherent Model Innova 100-K3 krypton ion laser.

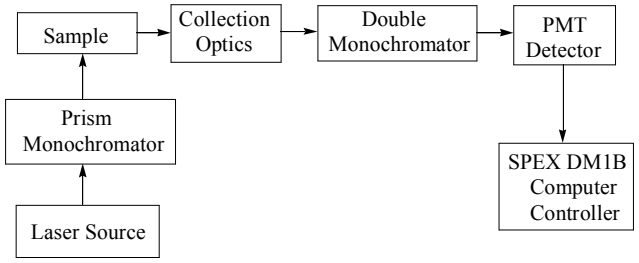


Figure 3. Block diagram of the instrument used for acquisition of ground state resonance Raman spectra.

Spectra of the complex were obtained from aqueous solution in a rotating NMR tube. The RR spectra of the complex at various excitations in aqueous solution are shown in Figure 4.

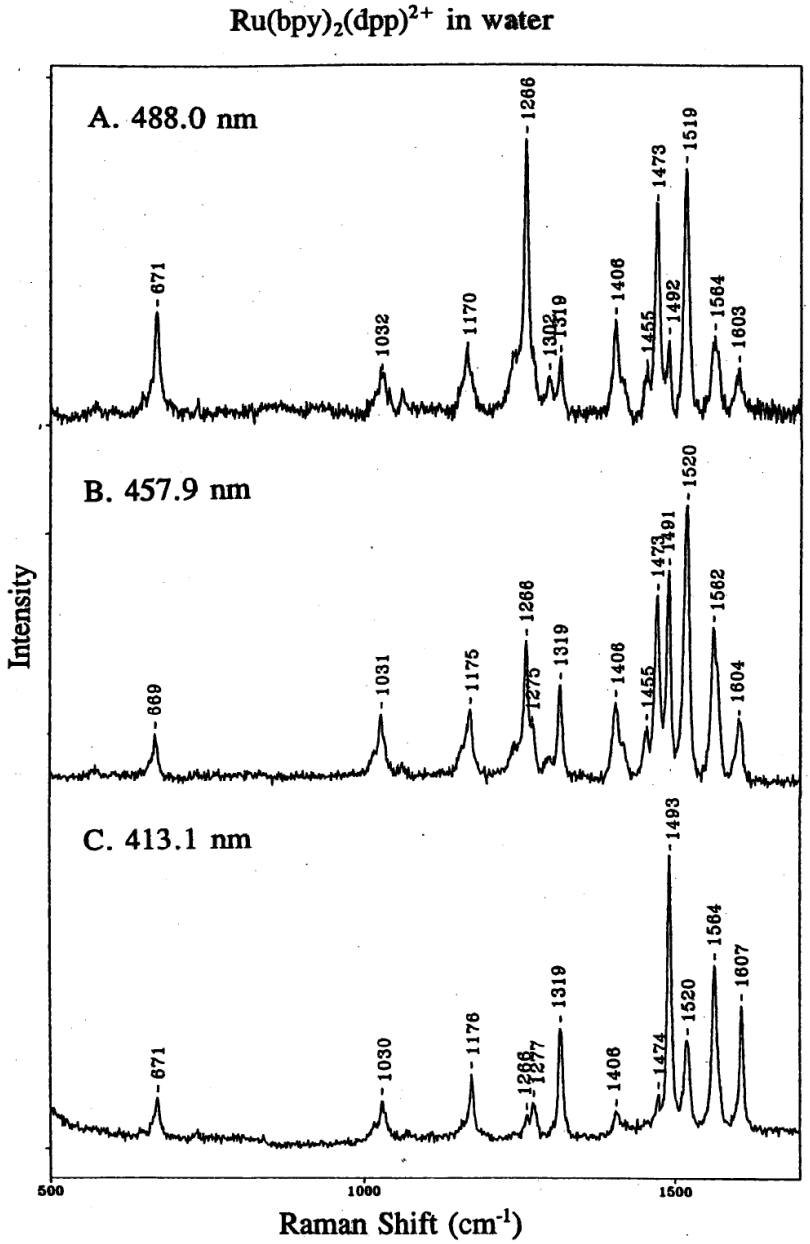


Figure 4. Ground state resonance Raman spectra of aqueous solution of $Ru(bpy)_2(dpp)^{2+}$ complex taken with excitation at 488 nm (trace A), 457.9 nm (trace B), and 413.1 nm (trace C).

The spinning 5 mm i.d. NMR tube (to prevent local overheating and sample decomposition) was illuminated by a laser beam focused through a glass lens, and the scattered light was collected with a conventional two-lens collection system. The frequencies of the complex are in good agreement with the literature (Braunstein et al. 1984, Bhuiyan and Kincaid 1999).

The spectra of $Ru(bpy)_2(dpp)^{2+}$ complex consist of bpy vibrations as well as dpp vibrations. The bpy vibrations can easily be identified by comparison with the well documented spectrum of $Ru(bpy)_3^{2+}$ complex (Danzer and Kincaid 1990). The additional vibrations at 1266, 1473, and 1519 cm^{-1} were assigned to dpp ligand in a report by Braunstein et al. (1984). In addition to those three bands, there are more dpp bands that overlap with the bpy bands. The dpp vibrations consist of three subsets. One set of bands (such as 1603 and 1170 cm^{-1} in Figure 4) is associated with the pyridine fragment of the dpp ligand which overlaps the bpy bands, the second set (such as 1519 and 1473 cm^{-1} in Figure 4) is associated with the pyrazine fragment of dpp ligand which has frequencies quite similar to those

of coordinated bipyrazine. A third set of vibrations has contributions from both fragments (such as 1319 and 1266 cm^{-1} in Figure 4) and are attributed to the inter-ring and adjacent bond stretching.

Resonance Raman spectra of the $Ru(bpy)_2(dpp)^{2+}$ complex were measured at 488.0, 457.9 and 413.1 nm excitation wavelengths. These spectra are readily understood on the basis of selective enhancement with the specific MLCT absorption bands. The RR spectra exhibit a revealing dependence on the excitation wavelength. The visible absorption spectrum of $Ru(bpy)_2(dpp)^{2+}$ consists of bands ~424 nm and ~474 nm. Excitation (488.0 nm) within the lower energy MLCT transition selectively enhances dpp modes relative to bpy modes (1519 vs 1492 cm^{-1} in trace A, Figure 4). On the other hand, excitation (413.1 nm) near resonance with the higher energy MLCT transition results in strong enhancement of the bpy modes (1493 vs 1520 cm^{-1} in trace C, Figure 4). Excitation with 457.9 nm, which is intermediate between the absorption bands, moderately enhances both bpy and dpp bands (trace B, Figure 4). The results of these studies permit the definitive assignment of the ground state absorption bands. The identities of the observed visible absorption bands are clearly established upon careful comparison of the resonance Raman spectra taken at various excitation wavelengths. From the selective enhancement of the RR experiment, the lower energy band is assigned to a Ru → dpp electronic transition, and the higher energy band is ascribable to a Ru → bpy electronic transition. We can exploit this strategy to provide unambiguous assignments of the absorption spectra for many bis-heteroleptic complexes of ruthenium (II), $Ru(L)_n(L')_{3-n}^{2+}$, where, L = 2,2'-bipyridine, L' = bpy related ligands. Alternatively, if we know the identity of absorption bands, then we can characterize the vibrational modes certainly from the selective enhancement of RR data.

Acknowledgments

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Growth Rate Calculations for Epitaxially Grown Thin Films

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Artificially fabricated semiconductor structures were introduced more than 20 years ago with some spectacular results in both basic physics discoveries and in commercial applications (Maclean 2001). Quantum well lasers, for example, are now found in every compact disc (CD) and digital video disc (DVD) player. The quantum well laser is a prime example of what has been termed a first-generation quantum device that is a device that reproduces the function of its respective conventional bulk device but with higher performance specifications (e.g., more stability over a broader temperature range). Second-generation quantum devices (still in the research stage) are multi-functional; a single structure can accomplish a task that would normally require as many as 10 conventional devices. A factor of 10 reduction in the number of components naturally leads to a significant increase in speed as well as a reduction in power consumption.

These multi-functional devices will require the production of complex structures with very short period superlattices, non-linear graded composition profiles, gross alterations in the lattice constant, etc. The key to accomplishing this goal is to have precise, atomic-scale control of the growth process. Unlike Si-based devices, which are primarily fabricated using implantation techniques, the III-V semiconductors require atomic layer-by-layer growth of the heterostructures (Current 1992). The remarkable advances that have been made over the past decade in a variety of advanced structures involving III-V compound semiconductors has come about primarily due to the advent of, and refinements in, the primary fabrication technique known as molecular beam epitaxy (MBE).

Semiconductor device fabrication via MBE growth occurs in an ultra-high vacuum (UHV) environment ($\sim 10^{-11}$ Torr) where a molecular beam of group III and group V molecules impinges on a single crystalline substrate. In MBE the mean free path for the impinging flux is much greater than the distance from source to sample, consequently the growth kinetics are determined by the relative sticking coefficients of the two species, by the diffusion rate of the two species once they are in contact with the substrate surface, and by the dissociation rate of the molecules.

Although MBE produces the highest quality samples, it has one major drawback; it is a very expensive technique to implement on a production scale. A basic production MBE system can cost upwards of ten million dollars. In addition to the equipment cost, both the consumables associated with running the machine as well as the required manpower create large overhead costs for the manufacturer. Consequently, it is of great interest to make the MBE production process as efficient as possible. One major source of production downtime comes while calibrating the most important aspect of the production, namely, the growth rate. It can take several days for a manufacturer to calibrate the growth rate from a source material in order to get the appropriate atomic ratios. Naturally, a better understanding of the physics governing the growth rate of these materials could enhance the efficiency of the MBE manufacturing process. What is needed is a model that can accurately predict the fraction of atoms that evaporate from the source material and arrive at the sample substrate to contribute to the growth of the structure.

Accurately predicting the growth rate is a difficult problem to solve because it is related to both static (such as the temperature of the material and the residual vacuum chamber pressure) and dynamic variables (such as the source-sample distance and solid angle) (Herman et al. 1989). However, with recent advances in both dynamic computational techniques and microcomputers, solution of this problem is possible. Our approach is to develop a model that describes the growth rate as it relates to the source temperature and geometry (i.e. solid angle and source-sample distance). Ideally, this model will have sub-monolayer accuracy and be computationally efficient.

The growth rate model will describe the molecular beam flux evaporating from the metallic Gallium (Ga) source and impinging on the surface of a GaAs substrate. This is directly related to Ga's vapor pressure. A material's vapor pressure, P, determines the number of atoms that evaporate from a sample's surface as a function of temperature (Tsao 1993). The complete temperature dependence of vapor pressure requires a formula with four adjustable constants. Many formulas have been suggested, but the one found

to be the most accurate by Nesmeyanov (Nesmeyanov 1963) is

$$\log P = D - \frac{A}{T} + CT + B\log T \,. \qquad (1)$$

In this equation, T is the temperature (in Kelvin) and A, B, C, and D are fitting parameters.

In order to develop an accurate model of the growth rate, it is necessary to determine which terms in the vapor pressure equation are the most dominate. In Figure 1 each individual term is plotted with its appropriate fitting constants for Ga. The log P is also plotted on the graph. From examining Figure 1 we see that the vapor pressure curve is dominated by the A/T term from equation 1. The next dominant term is determined to be the B log T term. In order to

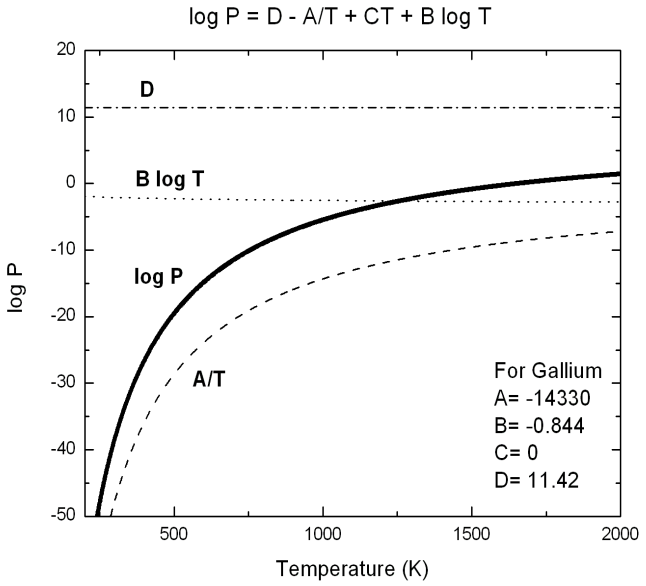

Figure 1. Graph illustrating the dependence of each term in the vapor pressure equation using the appropriate constants for Gallium as a function of absolute temperature. From this the dominating term (A/T) is ascertained.

simultaneously maximize the accuracy of our model but minimized computation time it is necessary to keep only the two most dominant terms from equation (1). Equation (1) then becomes

$$\log P = -\frac{A}{T} + B\log T \,. \qquad (2)$$

From equation (2) the vapor pressure equation is found to be

$$P = 10^{-\frac{A}{T}} T^{B} \,. \qquad (3)$$

Equation (3) assumes a uniform spherical distribution of evaporating material. This assumption will not apply in MBE since it takes advantage of highly directional Knudsen effusion cells (or K-cells) (Herman et al. 1989). To correct for this a new constant, GR_0, is introduced that scales the modified vapor pressure for the geometry of the K-cell and the source-sample distance. Equation (3) becomes the geometry corrected vapor pressure, $P_{GC,}$

$$P_{GC} = GR_0 \times P = GR_0 10^{\frac{-A}{T}} T^{B} \,. \qquad (4)$$

It is important to note that GR_0 will be constant only for a single growth since the source-sample distance and the solid angle between the source and sample will change for each successive production run requiring a new value for GR_0 to be calculated. This can be accomplished by measuring the temperature for a selected growth rate and using this information to solve for GR_0. In equation (4) the constant $A = E_a/k_B$ where E_a is the activation energy and k_B is Boltzmann's constant with a value of 8.617×10^{-5} eV/K. The activation energy is a parameter that describes the amount of energy required to completely remove an atom from the surface of the bulk material, for Gallium metal E_a = -1.457 eV. The fitting parameter B is related to the latent heat of the material and is found to have a value of -9.4101 (Nesmeyanov 1963). The growth rate equation is then expressed as

$$GR(T) = GR_0\, 10^{\frac{-E_a}{k_B T}} T^{B} \,. \qquad (5)$$

Figure 2 shows the derived growth rate equation has excellent agreement with experimentally determined growth rates (LaBella 2000).

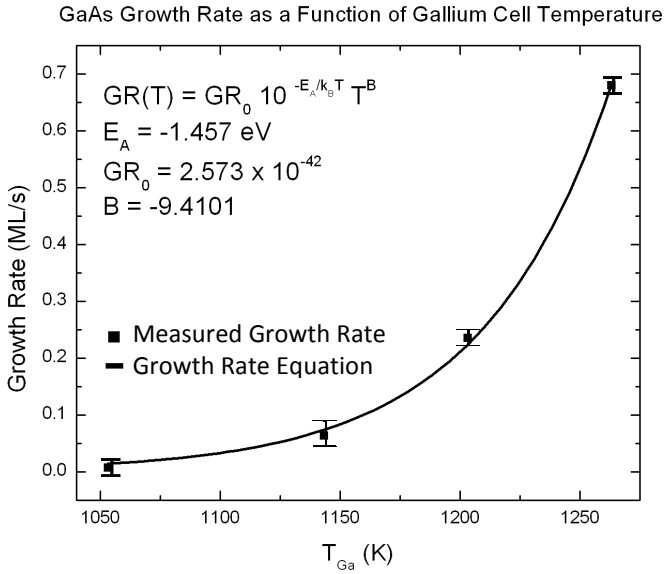

Figure 2. Graph illustrating the GaAs growth rate as a function of Gallium cell temperature. The line represents the developed formula which is graphed with actual growth rate data.

To further enhance the productivity of MBE systems it is necessary to provide immediate growth rate feedback to the user. Using equation (5), it was possible to develop a program to calculate the appropriate K-cell temperature for a desired growth rate. To do this the user inputs values for the current cell temperature, current growth rate, and the desired growth rate. Using this information the computer first calculates GR_0. Next, the calculation of the K-cell temperature is performed unfortunately due to the transcendental nature of equation (5) it is impossible to solve for the temperature algebraically, instead a numerical technique must be utilized that finds the root of the equation given the input parameters (Press et al. 2002). This root corresponds to the K-cell temperature that yields the desired growth rate.

In conclusion we have been successful at developing a model that predicts the growth rate as a function of temperature. This model agrees well with experimentally measured growth rates. Additionally, we have also developed software that can greatly reduce the time needed for growth rate calibrations.

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Two Coreidae (Hemiptera), *Chelinidea vittiger* and *Anasa armigera*, New for Arkansas, U.S.A.

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Most leaf-footed bugs (Hemiptera: Coreidae) occurring north of Mexico are essentially generalist phytophagous insects feeding on tender shoots or leaves. However, a few species are more specialized and feed on specific host plants or certain cultivated plants. The prickly pear cactus bug, *Chelinidea vittiger* Uhler 1863, is a specialist that feeds on *Opuntia* spp. We newly report this species for Arkansas. We found several specimens of this bug inhabiting a small, fractionated stand of *Opuntia* spp. growing on the crest of Devils Knob Natural Area in Izard County, Arkansas (Figure 1).

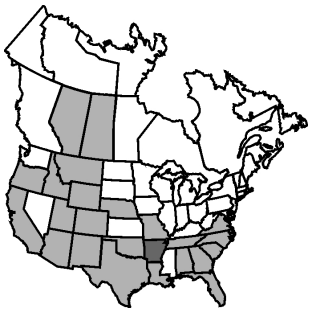
Specimens were collected directly from the pads of the cacti using long handled forceps and preserved in 70% ethanol. Herring (1980) was used for species identification. Chordas *et al.* (2005), Froeschner (1988), Herring (1980), and Maw *et al.* (2000) were used as distributional and faunal references. Voucher specimens were deposited into the C.A. Triplehorn Insect Collection (The Ohio State University, Columbus Ohio), the Carnegie Museum of Natural History (Pittsburgh, Pennsylvania), and the first author's collection (SWAC collection, Columbus Ohio).

The range of this species spans the southern and western United States and extends north into western Canada. It is absent, or at least undocumented, from the Great Lakes region even though stands of the host plant (*Opuntia* spp.) are present in the region (author's personal observations). It has also been reported from Mexico and was introduced into Australia as a biological control for exotic *Opuntia* spp. (Herring 1980). The occurrence of this coreid in Arkansas was expected as it has been reported for five surrounding states (Figure 2). We provide a current distribution north of Mexico for this species (Figure 2) since it has now been 20 years since a comprehensive treatment of its distribution was provided by Froeschner (1988) and several records have been added since that time.

Two of the four species of *Chelinidea* known to occur in the United States are now known for Arkansas. *Chelinidea canyona* Hamilton, 1923 is also known for the state (Herring 1980). We follow Herring (1980) and Froeschner (1988) in not recognizing subspecies of *Chelinidea vittiger* (which were almost solely based on color variations).

Collection Site: Arkansas, Izard County. Devils Knob Natural Area, off State Route 9. on *Opuntia* sp. 10 April 2005: Steve W. Chordas III & Peter W. Kovarik. N35.02 : W-92.05 : 2 - ♂ : 4 - ♀

Figure 1. Arkansas collection site of *Chelinidea vittiger.*



Alabama
Arkansas
Arizona
California
Colorado
Florida
Georgia
Idaho
Louisiana
Missouri
Montana
North Carolina
New Mexico
Nebraska
Oklahoma
Oregon
South Carolina
Tennessee
Texas
Utah
Virginia
Wyoming

+ Alberta
Saskatchewan
(*Canada*)

Also from
Mexico &
Australia

Figure 2. Distribution of *Chelinidea vittiger* north of Mexico.

We also newly report the horned squash bug, *Anasa armigera* Say 1825, for Arkansas. As with many members of this genus (i.e. *Anasa tristis* DeGeer, 1775: the common squash bug, which is also known for Arkansas), the horned squash bug commonly feeds upon cultivated or wild cucurbitaceous plants. While both of these species can be pests, *Anasa armigera* is not considered to be the major pest species.

This species was collected by general sweepneting in riparian vegetation of a wetland area outside of Heber Springs, Arkansas (Figure 3). Blatchley (1926) was used for species identification. Blatchley (1926), Chordas *et al.* (2005), Froeschner (1988), and Maw *et al.* (2000) were used as distributional references. The

single specimen was preserved in 70% ethanol and deposited in the first author's collection (SWAC collection, Columbus, Ohio).

The range of this species extends across the eastern United States and extends north into eastern Canada (Figure 4). Although we did not find a literature record for Kentucky for this species, we did find that the University of Kentucky Department of Entomology lists this species on their web page (www.ca.uky.edu/entomology) as one of the "common Kentucky leaf-footed bugs". Pictures of the bug, identification information, frequency of occurrence, host plant and pest information are all provided. Thus, we include it for Kentucky in our distribution map (Figure 4, shaded different to indicate the above). The occurrence of this coreid in Arkansas was expected as it has been reported for five surrounding states (Figure 4). We also provide a current distribution north of Mexico for this species (Figure 4) as it has now been 20 years since a comprehensive treatment of its distribution was provided by Froeschner (1988) and several records have been added since that time.

Two of the 6 *Anasa* species known for the United States are now reported for Arkansas. Up to 3 other *Anasa* species (*A. andresii* (Guerin-Meneville, 1857); *A. repetita* Heidenann, 1905; *A. scorbutica* (Fabricius, 1775)) may occur in the state (see Froeschner 1988).

Collection Site : Arkansas, Cleburne County. Wetland area on State Route 110. Steve W. Chordas III. 9 July 2005 : sweepnet. N35.5 : W-92.2 : 1-♂

Figure 3. Arkansas collection site of *Anasa armigera.*

Arkansas
Connecticut
D. C.
Delaware
Florida
Georgia
Iowa
Illinois
Indiana
Kansas
Kentucky
Louisiana
Massachusetts
Maryland
Michigan
Mississippi
Missouri
North Carolina
New Jersey
New York
Ohio
Oklahoma
Pennsylvania
South Carolina
Texas
Virginia
+ Ontario
Quebec
(*Canada*)

Figure 4. Distribution of *Anasa armigera* North of Mexico.

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Two Lygaeoidea (Hemiptera), *Ischnodemus slossonae* and *Cryphula trimaculata*, New for Arkansas, U.S.A.

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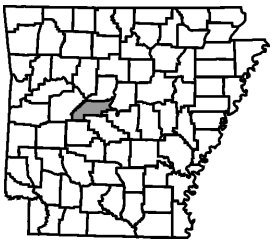
We report *Ischnodemus slossonae* Van Duzee, 1909 (Blissidae) and *Cryphula trimaculata* (Distant, 1882) (Rhyparochromidae) as new state records for Arkansas. We collected both macropterous and brachypterous forms of *I. slossonae* in Perry County from dip net samples (Figure 1). Apparently the insects were residing on vegetation protruding through the water and were knocked into the net during sweeping. This species is uncommon, but was not unexpected for Arkansas as it is known from 2 adjacent states (Figure 2). Slater (1979) was used for species identification. Voucher specimens were deposited into the C.A. Triplehorn Insect Collection (The Ohio State University, Columbus Ohio), the United States National Museum (Smithsonian, Washington D.C.), and the first author's collection (SWAC collection, Columbus Ohio). We thank Tom Henry (USNM, Washington D.C.) for verification of our identification.



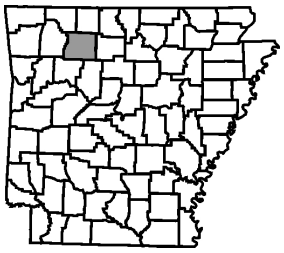
Collection site : Arkansas, Perry County. River-side flooded area & vegetation at State Route 216 bridge over the Fourche LaFave River: Dipnet: 10 April 2005: Steve W. Chordas III & Peter W. Kovarik : N35.00 : W-92.72 : 5-♂ : 4-♀

Figure 1. Arkansas collection site for *Ischnodemus slossonae.*

Arkansas
Connecticut
Florida
Kansas
Missouri
North Carolina
Texas

Figure 2. Distribution of *Ischnodemus slossonae* North of Mexico.

Ashlock and Slater (1988), and Maw *et al.* (2000) were used as distributional references for both species. Scudder (1962) was used for species identification of *C. trimaculata,* which was collected in Newton County (see Figure 3). Arkansas is within this species range and was expected for the state. We include current distribution maps for both species (Figures 2 and 4) as it has been 20 years since comprehensive distributions were provided by Ashlock and Slater (1988).



Collection Site : Arkansas, Newton County: Alum Cove, 4.75km north of Deer, Arkansas. 23 February 2003: Henry W. Robison, collector: N35.84 : W-93.20 : 1 specimen, retained by the first author.

Figure 3. Arkansas collection site for *Cryphula trimaculata*.

Arkansas
Colorado
Connecticut
Florida
Iowa
Illinois
Indiana
Kansas
Massachusetts
Missouri
North Carolina
New Jersey
New York
Ohio
South Carolina
+ Ontario (Canada)

Figure 4. Distribution of *Cryphula trimaculata* North of Mexico.

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New Distributional Records of Ants in Arkansas

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The importance of ants in environmental studies has been increasingly recognized. The ants of Arkansas have been poorly studied, and the original published list and identification keys (Warren and Rouse 1969) are outdated. We document here new distributional records for the state.

In an intensive study of the ants of Arkansas Post National Memorial in Arkansas County (General and Thompson 2007), LCT employed sugar-bait trapping and pitfall trapping for several years and DMG employed plot techniques, including: breaking into rotten wood of various sizes to search for nests, leaf litter sifting and Berlese extraction, peanut butter baiting on tree trunks, and searching visually for foragers on the ground, tree trunks, and foliage. Since then, in additional limited surveys in Drew County (3 sites on the UAM school forest) and Newton and Pope Counties (1 site each), we selected patches of forest that had large trees, thick leaf litter, downed coarse woody debris, and little evidence of recent disturbance. To sample ants, we used the plot collecting techniques as described above and detailed in (General and Thompson 2007), but without tree baiting. Our specimens from Craighead County were collected by T McKay at Arkansas State University, from poultry carcasses left out in a field as part of her forensic entomology classes.

The most appropriate and latest taxonomic references were used to identify the ants (Bolton 1994, 2000, Bolton et al. 2007, Brown 1960, Creighton 1950, Johnson 1988, MacGown 2006, Smith and Wing 1954, Snelling 1988, 1995, Taylor 1967, Trager 1984, 1991, Trager et al. 2007, Ward 1985, Warren and Rouse 1969, Wilson 1955, 2003). Problematic specimens, e.g., minor workers of *Pheidole* for which no identification keys exist, were shown to Stefan Cover of the Museum of Comparative Zoology (MCZ) at Harvard University for identification. Roy Snelling of the Los Angeles County Museum of Natural History corrected one determination (*Camponotus snellingi*) and verified others in the genus while he was visiting the MCZ.

Table 1 lists the ant species newly recorded in the state and in the 4 counties for which we have additional collections. Of note, even with our limited sampling in Newton and Pope Counties, we expanded the county totals from 1 species each (based on Warren and Rouse 1969) to 16 and 18, respectively. For Drew County the species count went from 3 to 32, and for Craighead County the few specimens examined expanded the ant species count from 9 to 11.

In all, there are 5 new records of ant species in the state and 68 new county records of species. This report suggests that a collective effort by entomologists statewide will likely result in many new distributional records.

Voucher specimens of new state records were deposited in the Arthropod Museum of the University of Arkansas in Fayetteville AR and in the MCZ in Cambridge MA. We acknowledge the field and lab assistance of Andres Bacon, Ted Kluender, John Stephens, and Robin Verble.

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Table 1. List of new ant species by subfamily from 4 counties in Arkansas.

#	SUBFAMILY/Species	County			
		Drew	Newton	Pope	Craighead
	AMBLYOPONINAE				
1	*Amblyopone pallipes*	X	X	X	
	DOLICHODERINAE				
1	***Dorymyrmex flavus***	●			
2	*Dorymyrmex insanus*	X			
	FORMICINAE				
1	*Camponotus americanus*	X	X		
2	*Camponotus castaneus*	X			
3	*Camponotus decipiens*	X			
4	*Camponotus nearcticus*		X	X	
5	*Camponotus pennsylvanicus*	X		X	
6	*Camponotus snellingi*	X	X		
7	*Formica pallidefulva*	X	X		
8	***Formica rubicunda***			●	
9	***Formica subsericea***			●	
10	*Paratrechina terricola*	X		X	
11	***Paratrechina wojciki***	●			X
	MYRMICINAE				
1	*Aphaenogaster carolinensis*	X			
2	*Aphaenogaster fulva*	X			
3	*Aphaenogaster lamellidens*	X			
4	*Aphaenogaster tennesseensis*		X	X	
5	*Aphaenogaster texana*	X	X	X	
6	*Crematogaster cerasi*	X			
7	*Crematogaster lineolata*		X	X	
8	*Crematogaster minutissima*	X		X	
9	*Monomorium minimum*	X			
10	*Myrmecina americana*	X	X	X	
11	*Myrmica punctiventris*	X		X	
12	*Pheidole dentigula*	X			
13	*Pheidole pilifera*	X			
14	*Pheidole tetra*				X
15	*Pyramica clypeata*	X	X		
16	*Pyramica ornata*	X	X	X	
17	*Solenopsis geminata*	X			
18	*Solenopsis invicta*	X			
19	*Solenopsis molesta*	X		X	
20	*Strumigenys louisianae*	X			
21	*Temnothorax curvispinosus*	X		X	
22	*Trachymyrmex septentrionalis*	X			
	PONERINAE				
1	*Cryptopone gilva*	X			
2	*Hypoponera opacior*	X			
3	***Ponera exotica***	●			
4	*Ponera pennsylvanica*	X	X	X	
	PROCERATIINAE				
1	*Discothyrea testacea*	X		X	
2	*Proceratium pergandei*		X		
3	***Proceratium silaceum***		X		
	from Warren and Rouse 1969	3	1	1	9
	New Records in County	32	16	18	2
	Number of Species in County	35	17	19	11

Key to Table 1
●= New AR Record of Species
X = New County Record of Species

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Acanthocephalan Parasites (Echinorhynchida: Heteracanthocephalidae; Pomphorhynchidae) from the Pirate Perch (Percopsiformes: Aphredoderidae), from the Caddo River, Arkansas

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The pirate perch, *Aphredoderus sayanus*, the only surviving member of the North American family Aphredoderidae, occurs throughout Arkansas in the Coastal Plain physiographic region and where it inhabits oxbow lakes, swamps, ditches, quiet ponds, and small rivers and streams (Lee 1980; Robison and Buchanan 1988). It is found in both clear and turbid water, often over a soft muddy bottom where it feeds on various invertebrates, especially insects (Becker 1983; Smith 1979). This fish is well-known for having the anus and urogenital openings jugular between the gill membranes in the adult where they migrated forward from the normal abdominal position in the juvenile during development (Page and Burr 1991).

The pirate perch has been the subject of several endoparasite surveys (Hopkins 1933; Elkins and Corkum 1976; Cooper 1996), some of which report acanthocephalan parasites from this host (Buckner and Buckner 1976; Williams 1976; Sukhdeo and Hernandez 2005; Hernandez et al. 2007). Herein we document new host and geographic records for 2 acanthocephalans from pirate perches from central Arkansas.

Four *A. sayanus* (mean = 30 ± 2.4, range = 27-33 mm standard length) were collected on 10 June 2002 with standard nylon seines (6 x 1.5 m and 9 x 1.5 m of 3.2 mm mesh) from the Caddo River at St. Hwy 7 bridge, Clark County (Sec. 31, T6S, R20W). They were placed in 10% formalin and returned to the laboratory for examination of helminth parasites. The entire gastrointestinal tract and coelomic cavity was examined. Acanthocephalans were transferred to 70% ethanol and shipped to the junior author (OA) for identification and further processing. Specimens were punctured with a fine needle and subsequently stained in Mayer's acid carmine, destained in 4% HCL in 70% ethanol, dehydrated in ascending concentrations of ethanol to 100% (24hr each), cleared in graduated (increasing) concentration of terpineol in 100% ethanol to 100%, then 50% terpineol and 50% Canada balsam (24 hr each), and finally whole mounted in Canada balsam. Voucher specimens of parasites were deposited in the United States National Parasite Collection (USNPC), Beltsville, Maryland. Voucher specimens of *A. sayanus* were deposited in the fish collection at Henderson State University, Arkadelphia, Arkansas as HSU 3185.

One of 4 (25%) pirate perches (33 mm) was found to be co-infected in the posterior intestine with a single pomphorhynchid acanthocephalan, *Pomphorhynchus lucyi* Williams and Rogers, 1984 (USNPC 100602), and 3 (2 males, 1 female) heteracanthocephalids closest to *Aspersentis* Van Cleave, 1929 (USNPC 100603). The specimen of *P. lucyi* possessed 15 proboscis hooks per row rather than 20-23, which is more typical of the species (Williams and Rogers 1984). However, all other morphological characteristics fit the description of *P. lucyi* (see Amin et al. 2003 for key to species).

The type host of *P. lucyi* is the lake chubsucker, *Erimyzon sucetta* from Florida (Williams and Rogers 1984). Other hosts include several species (and families) of fresh and brackish water fishes of the southeastern Gulf Coast of the United States (primarily Alabama and Florida), including *Amia calva*, *Notemigonus chrysoleucus*, *Opsopoeodus emiliae*, *Carpiodes velifer*, *Minytrema melanops*, *Lepomis auritis*, *L. gulosus*, *L. macrochirus*, *L. marginatus*, *L. microlophus*, *L. punctatus*, *Stronglura marina*, *Anguilla rostrata*, and *Ameiurus serracanthus* (Williams and Rogers 1984). Eleven of these hosts occur in the Caddo River (Robison and Buchanan 1988).

Interestingly, heteracanthocephalids are parasites of fishes in New Zealand, the former Soviet Union, Antarctica, and the Kerguelen and Falkland Islands (Amin 1982), and *Aspersentis* spp. are parasites of fishes in Antarctic and subAntarctic regions (Zdzitowiecki and White 1996; Palm et al. 1998; Zdzitowiecki 1981, 2001; Pichelin et al. 2002; Laskowski and Zdzitowiecki 2004, 2005). Unfortunately, our 3 specimens of heteracanthocephalids were contracted which rendered them less taxonomically informative than desirable for

definitive identification beyond family. Nevertheless, both acanthocephalans represent new host and noteworthy geographic records. In the future, we suggest a clinal study on *P. lucyi* as well as specific attempts at obtaining relaxed specimens of the heteracanthocephalids for specific identity.

Acknowledgments

We thank the Arkansas Game and Fish Commission for a Scientific Collecting Permit issued to CM and Patricia Pilitt (USNPC) and Dr. Renn Tumlison (HSU) for curatorial assistance.

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Eimeria wenrichi (Apicomplexa: Eimeriidae) from the Woodland Vole, *Microtus pinetorum* (Rodentia: Cricetidae), in Central Arkansas: A New Host and Geographic Record

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The woodland vole, *Microtus pinetorum* (LeConte) is a small semi-fossorial rodent that ranges throughout most of the eastern United States and extreme southern Ontario, Canada (Smolen 1981). In Arkansas, *M. pinetorum* can be found statewide, with the race *M. p. nemoralis* Bailey occurring in the Interior Highlands and *M. p. auricularis* Bailey occupying most of the Gulf Coastal Plain (Sealander and Heidt 1990).

Much is known about the ecology of this vole, including information on its ecto- and endoparasites (see Smolen 1981 for review). Although numerous coccidian parasites (Apicomplexa) have been reported previously from several other voles worldwide (Saxe et al. 1960; Winchell 1977; Vance and Duszynski 1985; Duszynski et al. 2007), the woodland vole has never been reported as a host. Herein, we document a new host and geographic record for a coccidian parasite.

During September 1992, December 2004 and April 2005, 7 *M. p. nemoralis* were collected with Sherman live traps or by hand from Craighead (n = 2) and Hot Spring (n = 1) counties, Arkansas, and Bowie (n = 4) County, Texas. Voles were killed by cervical dislocation and a mid-ventral incision was made to expose fecal contents. Feces was collected and placed in individual vials containing 2.5% (w/v) aqueous potassium dichromate ($K_2Cr_2O_7$) and examined by light microscopy following flotation in Sheather's sugar solution (specific gravity = 1.30). Negative samples were discarded and one positive sample collected on 9 April 2005 with unsporulated oocysts was allowed one week of sporulation at room temperature (ca. 23°C) in a Petri dish containing a thin layer of 2.5% $K_2Cr_2O_7$. Oocysts were concentrated again 4 months later with Sheather's and examined using a compound microscope equipped with Nomarski interference-contrast (DIC) optics. At a much later date (February 2008) this sample was examined again and 11 oocysts were photographed and measured using Olympus Microsuite© software. Measurements are reported in micrometers (µm) with means followed by the ranges in parentheses. Oocysts were ca. 1,395 days old when measured and photographed. Standardized abbreviations for characteristics of oocysts and sporocysts are per Wilber et al. (1998) as follows: oocyst length (L) and width (W), their ranges and ratios (L/W), micropyle (M), oocyst residuum (OR), polar granules (PG), sporocyst length (L) and width (W), their ranges and ratio (L/W), Stieda body (SB), substieda body (SSB), parastieda body (PSB), sporocyst residuum (SR), refractile bodies (RB), and nucleus (N). A photovoucher of sporulated oocysts were accessioned into the United States National Parasite Collection, Beltsville, Maryland as USNPC 100690. A host voucher specimen was deposited in the Angelo State Natural History Collection (ASUMZ), San Angelo, Texas as ASNHC 13004.

A single *M. p. nemoralis* collected off St. Hwy 128 at DeRoche, Hot Spring County (34.19492°N, 93.02513°W) was found to be passing oocysts of a coccidian fitting the description of *Eimeria wenrichi* Saxe, Levine and Ivens, 1960 (Fig. 1). One interesting morphological exception of the oocysts we recovered to the original description of *E. wenrichi* by Saxe et al. (1960) was that the SR was dispersed and not a compact mass. However, this could be due to the age of the material. Oocysts (n = 11) were ovoidal, L X W = 18.8 X 13.5 (15.4-20.9 X 12.1-14.9), PG present, oocyst wall single layered, with no OR; sporocysts were ovoidal, L X W = 9.9 X 6.0 (9.3-10.5 X 4.5-7.3), SB clear or dark and nipple-like, SR dispersed into small and large granules.

Eimeria wenrichi (syn. *E. wenrichi* "A") was originally described from the meadow vole, *M. pennsylvanicus* from Pennsylvania. Since then the species has been reported from numerous other voles from the world (Table 1). Vance and Duszynski (1985, Fig. 12) provided the first published photomicrograph of an oocyst of *E. wenrichi* from *Microtus mexicanus subsimus* from Coahuila, Mexico, which compare favorably to oocysts we describe herein (Fig. 1).

Table 1. Reported worldwide hosts of *Eimeria wenrichi*.

Microtus sp./spp.	Locale	Prevalence*	Reference
breweri	Natucket Co., MA	320/410 (78%)	Winchell (1977)
longicaudus	AK**	3/29 (10%)	Duszynski et al. (2007)
mexicanus fluviventer	Oaxaca, MX	1/26 (4%)	Vance and Duszynski (1985)
m. mexicanus	Veracruz, MX	4/15 (3%)	Vance and Duszynski (1985)
m. mogolloensis	Apache Co., AZ	1/1 (100%)	Vance and Duszynski (1985)
m. subsimus	Coahuila, MX	8/48 (8%)	Vance and Duszynski (1985)
miurus	AK**	39/88 (44%)	Duszynski et al. (2007)
montanus arizonensis	Apache Co., AZ	4/8 (50%)	Vance and Duszynski (1985)
oeconomus	AK**	265/405 (65%)	Duszynski et al. (2007)
	Siberia, Russia**	29/48 (60%)	Duszynski et al. (2007)
o. oregoni	Clallam Co.,WA	2/4 (50%)	Vance and Duszynski (1985)
p. pennsylvanicus	PA	1/1 (100%)	Saxe et al. (1960)
	Franklin Co., MA	5/11 (45%)	Vance and Duszynski (1985)
	AK**	123/159 (77%)	Duszynski et al. (2007)
pinetorum nemoralis	Hot Spring Co., AR	1/1 (100%)	This study
xanthognathus	AK**	9/52 (17%)	Duszynski et al. (2007)

*Prevalence in collected samples = number infected/number examined (percent); note low sample sizes in some reports.
**See Duszynski et al. (2007) for specific locales in Alaska and northeastern Siberia, Russia
.

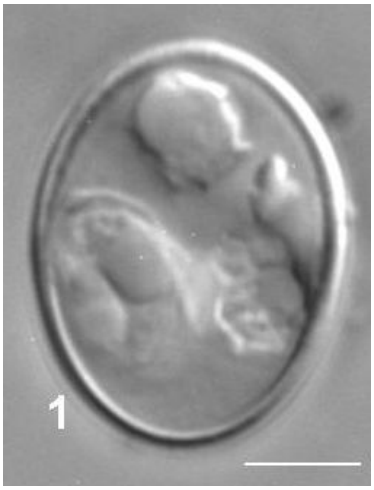

Figure 1. Sporulated oocyst of *Eimeria wenrichi* from *M. p. nemoralis* from Hot Spring County, Arkansas. Scale bar = 5 μm.

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New Records of Eurymerodesmid Millipeds (Diplopoda: Polydesmida) from Arkansas, Kansas, Louisiana, Oklahoma, and Texas

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The milliped family Eurymerodesmidae occupies a variety of habitats in the central, southcentral, and southeastern United States; it ranges from northeastern NE, central IL, and southeastern NC to the Rio Grande and nearly to Tampa Bay, FL (Shelley 1990). The only component genus is *Eurymerodesmus* Brölemann, 1900, which comprises 25 species, nearly half of which (11 or 44%) occur in LA. *Eurymerodesmus mundus* Chamberlin, 1931, occurs from NE to AR and TX (McAllister et al. 2004), and herein, we document it from LA and new sites in AR and OK. We also provide new records of *E. amplus* (TX), *E. angularis* (LA), *E. b. birdi* (AR, KS, and TX), *E. melacis* (TX), and *E. mundus* and *E. pulaski* (AR).

Between October 2001 and October 2003, locales in Caddo Parish (Par.) were searched for *E. mundus*. Other eurymerodesmids were sampled through December 2007 from sites in AR, KS, LA, NE, OK, SD, and TX, many being along trails in state parks. Specimens were collected from damp areas in mixed deciduous and pine forests by overturning decaying logs and leaf litter with potato rakes. They were placed in vials containing 70% ethanol, returned to the laboratory for processing and sorting, and shipped to RMS for determination to the lowest taxonomic level. Voucher specimens are deposited in the North Carolina State Museum of Natural Sciences (NCSM). All localities cited below constitute new county/parish records.

Eurymerodesmus mundus Chamberlin 1931

AR: *Scott Co*., Waldron, 6 January 2006, Waldron High School Students, ♂. **LA**: Caddo Par. near Ida, off US 71 and Munnerlyn Chapel Road (32°59.2'N, 93°53.5'W, elevation = 76 m), 24 October 2003, CTM ♂. **OK**: *Washita Co*., Crowder Lake St. Pk., 8 November 2003, CTM, ♂, ♀. This species occurs in Lafayette, Miller, Polk, and Sevier cos., AR (McAllister et al. 2004), and the above record is the northernmost in the state. In OK, *E. mundus* has been reported from 13 cos. (Fig. 1), the above record being the westernmost (McAllister et al. 2004). The LA male was under bark of a decaying pine log at the edge of deciduous forest that had been recently clear-cut. This record confirms McAllister et al.'s (2004) prediction of eventual discovery in this region of LA. The distribution is shown below in Fig. 1.

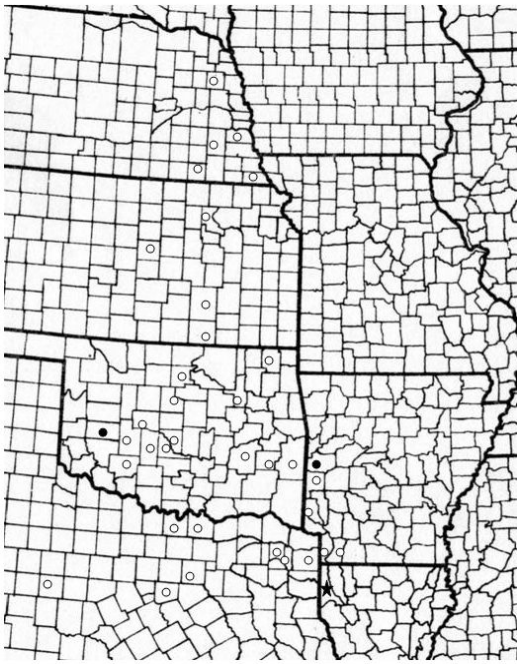

Figure 1. Distribution of *E. mundus*. Open circles (previous records); closed circles (new records); star (state record).

Eurymerodesmus amplus Causey 1952

TX: *Cherokee Co*., Caddoan Mounds State Historic Park, 1 March 2003, CTM, G. Torres, 8♂, 7♀, 3 juvs. *Freestone Co*., Fairfield Bay St. Pk. , 9.7 km NE Fairfield, 21 December 2002, CTM, J. T. McAllister, III, 3♂. *Hardin Co*., Village Creek St. Pk., Lumberton, 15 June 2004, CTM, ♂. *Limestone Co*., Confederate Reunion Grounds St. Pk. , 21 December 2002, CTM, J. T. McAllister, III, 3♂, 2♀. This milliped has been reported from several western parishes in LA and 18 cos. in east TX, and an allopatric population exists to the west in Mason Co., TX, on the Edwards Plateau region (Shelley 1990).

Eurymerodesmus angularis Causey 1951

LA: *Webster Par*., Lake Bistineau St. Pk., 1 January 2004, CTM, ♂. *Eurymerodesmus angularis* occurs in 6 LA pars., 7 cos. in AR, and 3 in TX (Shelley 1990; McAllister et al. 2004).

Eurymerodesmus birdi birdi Chamberlin 1931

AR: *Scott Co*., Lake Winkle, Waldron, 3 February 2006, S. Pickens, ♂. **KS**: *Cherokee Co*., 1.6 km S Galena off St. Hwy 26 at Schermerhorn Park, 4 May 2005, CTM, ♂. **TX**: *Cass Co*., Atlanta St. Pk., 3 October 2001, CTM, RMS, ♂. *Harrison Co*., Caddo Lake St. Pk., 12 November 2001, CTM, 3♂. This widely ranging milliped is known from AR, KS, LA, MS, MO, OK, and TX (Shelley 1990; McAllister and Shelley 2003; McAllister et al. 2002a,b, 2003a,b).

Eurymerodesmus melacis Chamberlin and Muliak 1941

TX: *Brown Co*., Brownwood St. Pk., 27 November 2002, CTM, ♂, juv. *Coleman Co*., 3.2 km E Talpa off US 67, 23 December 2006, CTM, 7♂. *Edwards Co*., 3.2 km SW Telegraph off US 377, 21 February 2004, CTM, 7♂. *Sutton Co*., Caves of Sonora, 18 November 2005, CTM, ♂♂, ♀♀, juv. *Eurymerodesmus melacis* is the westernmost congener in TX (Fig. 2), it inhabits caves on the Edwards Plateau, and is endemic in the state (Shelley 1990).

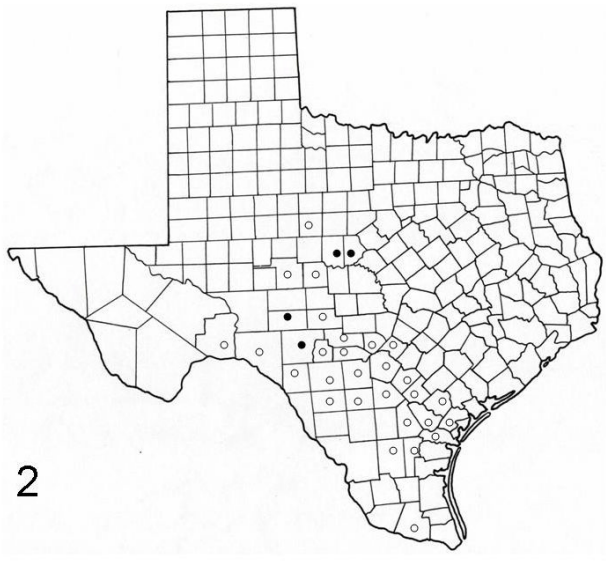

Figure 2. Distribution of *E. melacis* in TX. Open circles (previous records); closed circles (new records).

Eurymerodesmus pulaski (Causey 1950)

AR: *Saline Co*., 4.8 km S Shannon Hills, 26 December 2006, CTM, ♂, ♀, juv. Previously known only from Pulaski Co. (Shelley 1990; McAllister et al. 2002b, 2003a), *E. pulaski* was reported as "*Leptodesmus hispidipes*" by Bollman (1888) and *Paresmus pulaski* by Causey (1950); it was collected in the 1880s, 4.8 km south of Sweet Home by C. H. Bollman. Recent samples by McAllister et al. (2002b, 2003a) documented *E. pulaski* from Pinnacle Mountain St. Pk. and on the UALR campus and Rosedale Edition in western Little Rock. It is 1 of 5 endemic species of *Eurymerodesmus* in the state (Robison et al. 2008).

Interestingly, no eurymerodesmids were found by CM at several sites in northeastern NE or immediately north of the MO River watercourse in southeastern SD (Clay, Union and Yankton cos.), although there are records of *E. mundus* from Cass, Cuming, Jefferson, Lancaster, and Richardson cos., NE (Shelley 1990). This further supports the contention of Shelley (1990) that *Eurymerodesmus* probably does not occur in SD and the MO River is a boundary for the family.

Little milliped sampling has taken place recently in LA in general and the northwestern region in particular. Papers on the state's fauna include Chamberlin (1918a,b, 1920, 1942), Viosca (1919), Causey (1953, 1954, 1955, 1958, 1963), and Loomis (1959), and records can be gleaned from studies of taxa occurring there (Hoffman 1958; Shelley 1980, 1982, 1984a,b, 2002, 2006; Shelley and Golovatch 2000, Shelley and McAllister 2006). Northwestern LA is expected to harbor a diversity of species as suggested by studies in neighboring states (McAllister et al., 2002a,b, 2003a,b, 2004, 2005; McAllister and Shelley, 2005; Shelley et al. 2003a,b, 2005). Additional sampling in this region is recommended.

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Rabies Prevalence Among and New Distribution Records of Arkansas Bats

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Rabies has been known from Arkansas bats since 1961 and approximately 18% of cases of animal rabies in the state are accounted for by bats (Heidt 1982; Sasse 2004). General statistics on total bat submissions and rabies prevalence were summarized for 1950-1981 by Heidt (1982). McChesney et al. (1983) was the first to provide detailed information on this disease at the species level in Arkansas, though only for a single year. Heidt et al. (1987) reported on rabies in Arkansas bat species based on specimens submitted to the Arkansas Department of Health from 1982-1986 and later reported on specimens collected from 1982-1990 (Heidt et al. 1991). While most recent cases of human rabies in Arkansas and the United States come from contact with rabid bats, people in Arkansas are 17 times more likely to come in contact with rabid domestic animals such as cats and dogs (Sasse 2004).

In this paper, we describe rabies prevalence in Arkansas bat species and new bat species records from counties from which they had not been previously observed.

From 1983 to 2007, 2,566 bats were submitted to and tested for rabies by the Arkansas Department of Health and identified to species, sex, and age. Deteriorated specimens that could not be tested or could not be identified to species were not included in this study.

Bats were submitted for testing from all Arkansas counties except Clay, although only 7 counties, all of which contained urban areas, averaged more than 2 bat submissions per year. Most bats came from Pulaski (34.5%) and Garland (9.9%) Counties with no other county representing more than 4% of total submissions. Four species, *Lasiurus borealis*, *Eptesicus fuscus*, *Nycticeius humeralis*, and *Tadarida brasiliensis*, accounted for 87.8% of total submissions.

Overall rabies prevalence among all species was 9.5% (244/2566) and was highest in solitary tree-roosting species such as *L. seminolus* (44.4%), *L. cinereus* (29.4%), and *L. borealis* (16.8%) and was low in *E. fuscus* (3%) *and T. brasiliensis* (7.4%), colonial species which are most commonly found in Arkansas homes and other buildings. Care should be taken in interpreting rabies prevalence data for bats, especially for those species with small sample sizes, as specimens are collected in a biased matter, most often after exhibiting some form of unusual activity in the vicinity of human dwellings prior to being submitted for testing and true prevalence rates in bats are probably much lower (Blanton et al. 2007; Caire 1998).

Corynorhinus rafinesquii (Rafinesque's big-eared bat)

Eleven specimens, including a single rabid individual (9.1%), were received from 10 counties. One new distribution record was obtained from Howard County.

Eptesicus fuscus (Big brown bat)

Seven hundred twenty six specimens, including 22 (3.0%) rabid individuals, were received from 50 counties. New county distribution records were obtained from Boone, Calhoun, Crawford, Dallas, Fulton, Greene, Jackson, Jefferson, Johnson, Logan, Marion, Ouachita, Randolph, Union, Van Buren, and White Counties.

Lasionycteris noctivagans (Silver-haired bat)

Twenty-five non-rabid specimens were received from 14 counties. Specimens were submitted from September through March only, with the majority (52%) in November and December. New county distribution records were obtained from Carroll, Faulkner, Lawrence, Newton, Van Buren, and White Counties.

Lasiurus borealis (Red bat)

Nine hundred and forty seven specimens, including 159 (16.8%) rabid individuals, were received from 68 counties. Although this species comprised only 37% of total submission, it represented 65% of all rabid bats. Prevalence varied by age with 23.2% of adults and only 4% of juveniles testing positive for rabies. New county distribution records were obtained from Boone, Fulton, Madison, Marion, Searcy, and St. Francis Counties.

Lasiurus cinereus (Hoary bat)

Fifty-one specimens, including 15 (29.4%) rabid individuals, were received from 17 counties. Fourteen

juveniles submitted for rabies testing during the months of June and July from Jefferson, Pulaski, Saline, and Sebastian Counties provide additional evidence that this species breeds in Arkansas (Perry and Thill 2007). New county distribution records were obtained from Arkansas, Clark, Columbia, Howard, Lonoke, Randolph, and White Counties.

Lasiurus seminolus (Seminole bat)

Nine specimens, including 4 (44.4%) rabid individuals, were received from 7 counties. New county distribution records were obtained from Columbia, Randolph, Union, and Woodruff Counties.

Myotis austroriparius (Southeastern bat)

Four specimens, none of which were rabid, were received from 4 counties.

Myotis grisescens (Gray bat)

Thirty-three specimens of this endangered species, including 1 rabid individual (3.0%), were received from 10 counties. New county distribution records were obtained from Sebastian and Van Buren Counties. The specimen from Sebastian County, which represents a small range extension to the southwest, was a non-rabid adult male collected in Fort Smith on September 17, 2004.

Myotis leibii (Small-footed bat)

A single non-rabid adult male was obtained from Mena in Polk County on September 16, 1992.

Myotis lucifugus (Little brown bat)

Twenty-one specimens, none of which were rabid, were received from 13 counties. New county distribution records were obtained from Benton, Boone, Cleburne, Little River, Lonoke, Randolph, Van Buren, and White Counties.

Myotis septentrionalis (Northern long-eared bat)

Twenty-four specimens, none of which were rabid, were received from 11 counties. New county distribution records were obtained from Boone and Van Buren Counties.

Nycticeius humeralis (Evening bat)

Three hundred fifty specimens, including 7 rabid individuals (2.0%), were received from 45 counties. New county distribution records were obtained from Boone, Conway, Dallas, Faulkner, Jefferson, Johnson, Madison, Randolph, and Van Buren Counties.

Perimyotis subflavus (Eastern pipistrelle)

One hundred thirty three specimens, including 18 rabid individuals (13.5%), were received from 38 counties. New county distribution records were obtained from Arkansas, Cleburne, Columbia, Conway, Cross, Dallas, Desha, Grant, Hempstead, Hot Spring, Jefferson, Johnson, Randolph, and Sebastian Counties.

Tadarida brasiliensis (Brazilian free-tailed bat)

Two hundred thirty one specimens, including 17 rabid individuals (7.4%), were received from 21 counties. New county distribution records were obtained from Drew, Hot Spring, Perry, Saline, and Scott Counties.

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Title of a Paper Prepared for the Arkansas Academy of Science Journal (14 point, bold, centered)

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Instructions (11 point font, bold)

The *JOURNAL OF THE ARKANSAS ACADEMY OF SCIENCE* is published annually. It is the policy of the Arkansas Academy of Science that 1) at least one of the authors of a paper submitted for publication in the *JOURNAL* must be a member of Arkansas Academy of Science, 2) only papers presented at the annual meeting are eligible for publication, and 3) the manuscript is due at the time of presentation. Manuscripts should be e-mailed to Dr. Ivan Still, the Managing Editor of the Journal (istill@atu.edu) two days before the meeting. An electronic copy (on CD) and hard copy should be handed to the editorial staff at the meeting. The hard copy should include a separate title page with authors' names and addresses. The authors should obtain the signature of one of the editorial staff to acknowledge our receipt of the manuscript. After the meeting all correspondence regarding response to reviews etc. should be directed to the Managing Editor. Publication charges ($50 per page) are payable when the corresponding author returns their response to the reviewers' comments, and should be sent to the Editor-in-Chief, Dr. Mostafa Hemmati (mhemmati@atu.edu). Please note that the corresponding author will be responsible for the total publication cost of the paper. All manuscript processing, review and correspondence will be carried out electronically using e-mail. Thus, authors are requested to add the editors' e-mail addresses to their accepted senders' list to ensure that they receive all correspondence.

Manuscripts should be submitted either as a **feature article** or a shorter **general note**. Each submitted paper should contain results of original research, embody sound principles of scientific investigation, and present data in a concise yet clear manner. For scientific style and formal, the CBE Manual for Authors, Editors, and Publishers Sixth Edition, published by the Style Manual Committee, Council of Biology Editors, is a convenient and widely consulted guide for scientific writers and will be the authority for most style, format, and grammar decisions. Authors should use the active voice for directness and clarity. Special attention should be given to grammar, consistency in tense, unambiguous reference of pronouns, and logically placed modifiers. All prospective authors are strongly encouraged to submit their manuscripts to other qualified persons for a friendly review of clarity, brevity, grammar, and typographical errors before submitting the manuscript to the *JOURNAL*. To expedite review, authors should provide the names and current e-mail address of at least three reviewers within the appropriate field, with whom they have not had a collaboration in the past two years. Potential reviewers that the authors wish to avoid due to other conflicts of interest can also be provided.

Proposed timetable for manuscript processing

2 days before AAS annual meeting: authors e-mail manuscript to Managing Editor.
AAS annual meeting: authors submit electronic (on CD) and hard copy to editorial staff at the meeting.
End of May: Initial editorial review. Manuscripts sent to reviewers.
End of July: All reviews received. Editorial decision made on reviewed manuscripts. Manuscripts returned to authors for response to reviewers' critiques.
End of August: Authors return revised manuscripts 28 days after editorial decision/reviewers critiques were e-mailed. Corresponding author submits publication charges.

The prompt return of revised manuscripts and payment of publication costs is critical for processing of the journal by the journal staff. If the corresponding author will be unable to attend to the manuscript within the framework of this schedule, then it is the responsibility of the corresponding author to make arrangements with a coauthor to handle the manuscript. NB. The corresponding author will be responsible for submitting the total publication cost of the paper. Failure to pay the publication charges in a timely manner will prevent processing of the manuscript.

Preparation of the Manuscript

1. Use Microsoft Word 2003 or higher for preparation of the document and the file should be saved as a Word Document.
2. The text should be prepared in two columns and the distance between columns should be 0.5″.
3. Indent paragraphs and subheadings 0.25″
4. Use 11 point font in Times New Roman for text. Fonts for the rest of the manuscript must be
   a) Title: 14 point, bold, centered
   b) Authors' names: 12 point, normal, centered
   c) Authors' addresses: 10 point, italic, centered
   d) Main text: 11 point, justified left and right
   e) Figure captions: 9 point, normal
   f) Section headings: 11 point, bold, flush left on a separate line
   g) Subheadings: 11 point, bold, italic and flush left on a separate line
5. Top and Bottom margins should be set at 0.9″; Left and Right margins, 0.6″.
6. Set words in italics that are to be printed in italics (e.g., scientific names).
7. Indicate on the title page which author is the corresponding author and indicate that author's email address, phone number, and fax number.
8. **An abstract** summarizing in concrete terms the methods, findings, and implications discussed in the body of the paper must accompany a feature article. That abstract should be completely self-explanatory.
9. A **feature article** is 2 or more pages in length.
10. Most **feature articles** should include the following sections: Abstract, Introduction, Materials and Methods, Results, Discussion, Conclusions, Acknowledgments, and Literature Cited.
11. A **general note** is generally shorter, usually 1 to 2 pages and rarely utilizes subheadings. A note should have the title at the top of the first page with the body of the paper following. Abstracts are not used for general notes.
12. The **metric System of measurements** and weights must be employed. **Grams** and **Kilograms** are units of **mass** not weight. Standard distance measurements are permitted in parentheses.
13. In scientific text, **Arabic numerals** should be used in preference to words when the number designates anything that can be counted or measured: 3 hypotheses, 7 samples, 20 milligrams. However, numerals are not used to begin a sentence; spell out the number, reword the sentence, or join it to a previous sentence. Also, 2 numeric expressions should not be placed next to each other in a sentence. The pronoun "one" is always spelled out.
14. **Tables and figures** (Line drawings, graphs, or black and white photographs) should not repeat data contained in the text. Tables, figures, graphs, pictures, etc. have to be inserted inside the manuscript. Tables and figures must be numbered and have short captions. A caption should be written under each figure and above each table. Allow two spaces above and below figures/tables (unless the table/figure is at the bottom/top of the page). For tables, insert a solid 1.5 pt line below the caption and at the bottom of table. Within tables place a 0.75pt line under table headings or other divisions. Figure 1 shows an example for the format of a figure inserted inside the manuscript.

    In the event that a table, a figure, or a photograph requires larger space than a two column format will provide, the two column format should be ended and the illustration should be placed immediately after that. The two column format should continue immediately after that illustration.

    Should the table continue to another page, do not place a line at the bottom of the table. On the next page, place the heading again with a 0.75pt line below, then 1.5 pt line at start of table on the continued page.

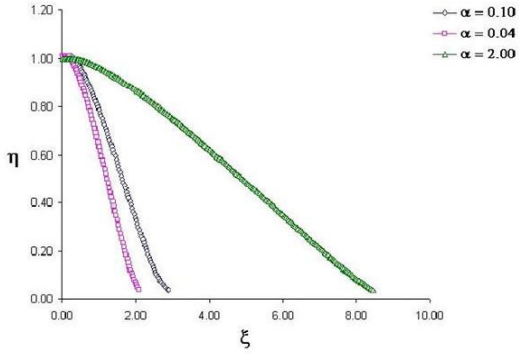

Figure 1. Electric field, η, as a function of position, ξ, within the sheath region for three different wave speeds, α.

15. Equation numbers must be in parentheses and placed flush with right-hand margin of the column.
16. Cataloguing and deposition of biological specimens into collections is expected. Publication of manuscripts will be contingent on citation of database accession numbers and/or voucher specimens. Collector and voucher number for each specimen should be stated in the Results section. The location of the collection should be stated in the Methods section. This will facilitate easy

access should another researcher wish to obtain and examine the specimen in question.

17. **Literature Cited:** Authors should use the Name – Year format as illustrated in *The CBE Manual for Authors, Editors, and Publishers* and as shown below. The *JOURNAL* will deviate from the form given in the *CBE Manual* only in regard to placement of authors' initials and abbreviation of journal titles. Initials for second and following authors will continue to be placed before the author's surname. **Journal titles should be written in full.** Formats for a journal article and a book are shown below along with examples. Note that authors' names are in bold, double spacing occurs after periods. References should be single line spaced, justified with second and following lines indented 0.25 inch. Column break a reference in Literature Cited that runs into the next column so that the entire reference is together. Insert a continuous Section break at the end of the references.

    Accuracy in referencing current literature is paramount. Authors are encouraged to use a reference databasing system such as Reference Manager or Endnote to enhance accurate citation. Do not cite abstracts and oral, unpublished presentations. Unnecessary referencing of the authors own work is discouraged; where possible the most recent reference should be quoted and appended with "and references therein".

General form:

Author(s). Year. Article Title. Journal title volume number(issue number):inclusive pages.

Author(s) [or editor(s)]. Year. Title of Book. Place of publication: publisher name. Number of pages.

Standard Journal Article

Davis DH. 1993. Rhythmic activity in the short-tailed vole, *Microtus*. Journal of Animal Ecology 2:232-8.
In text Citation: (Davis 1993)

Steiner U, JE Klein, and **LJ Fletters**. 1992. Complete wetting from polymer mixtures. Science 258(5080):1122-9.
In text Citation: (Steiner et al. 1992)

Zheng YF and **JYS Luh**. 1989. Optimal load distribution for two industrial robots handling a single object. ASME Journal of Dynamic System, Measurment, and Control 111:232-7.
In text Citation: (Zheng and Luh 1989)

In press articles

Author(s). Expected publication Year. Article Title. Journal title *in press*.
In text Citation: (First author et al. *in press*)

Kulawiec M, A Safina, MM Desouki, IH Still, S-I Matsui, A Bakin, and **KK Singh**. 2008. Tumorigenic transformation of human breast epithelial cells induced by mitochondrial DNA depletion. Cancer Biology & Therapy *in press.*

Electronic Journal Articles and Electronic Books should be cited as standard journal articles and books except add an availability statement and date of accession following the page(s).

653 p. Available at: www.usfw.gov/ozarkstreams. Accessed 2004 Nov 29.

Books, Pamphlets, and Brochures

Box GEP, WG Hunter, and **JS Hunter**. 1978. Statistics for experiments. New York: J Wiley. 653 p.
In text Citation: (Box et al. 1978)

Gilman AG, TW Rall, AS Nies, and **P Taylor, editors**. 1990. The pharmacological basis of therapeutics. 8th ed. New York: Pergamon. 1811 p.
In text Citation: (Gilman et al. 1990)

Engelberger JF. 1989. Robotics in Service. Cambridge (MA): MIT Press. 65p.
In text Citation: (Engelberger 1989)

Book Chapter or Other Part with Separate Title but Same Author(s) – General format is given first.

Author(s) or editor(s). Year. Title of book. Place of publication: publisher's name. Kind of part and its numeration, title of part; pages of part.

Hebel R and **MW Stromberg.** 1987. Anatomy of the laboratory cat. Baltimore: Williams & Wilkins. Part D, Nervous system; p 55-65.

Singleton S and **BC Bennett**. 1997. Handbook of microbiology. 2nd ed. Emmaus (PA): Rodale. Chapter 5, Engineering plasmids; p 285-96.

Book Chapter or Other Part with Different Authors – General format is given first.

Author(s) of the part. Year. Title of the part. *In* author(s) or editor(s) of the book. Title of the book. Place of publication: publisher. Pages of the part.

Weins JA. 1996. Wildlife in patchy environments: Metapopulations, mosaics, and management. *In*: McCullough DR, editor. Metapopulations and wildlife conservation. Washington, DC: Island Press. p 506.

Johnson RC and **RL Smith.** 1985. Evaluation of techniques for assessment of mammal populations in Wisconsin. *In* Scott Jr NJ, editor. Mammal communities. 2nd ed. New York: Pergamon. p 122-30.

Dissertations and Theses – General format is given first.

Author. Date of degree. Title [type of publication – dissertation or thesis]. Place of institution: name of institution granting the degree. Total number of pages. Availability statement.

The availability statement includes information about where the document can be found or borrowed if the source is not the institution's own library.

Millettt PC. 2003. Computer modeling of the tornado-structure interaction: Investigation of structural loading on a cubic building [MS thesis]. Fayetteville (AR): University of Arkansas. 176 p. Available from: University of Arkansas Microfilms, Little Rock, AR; AAD74-23.

Stevens WB. 2004. An ecotoxilogical analysis of stream water in Arkansas [dissertation]. State University (AR): Arkansas State University. 159 p.

Scientific and Technical Reports – General format is given first.

Author(s) (Performing organization). Date of publication. Title. Type report and dates of work. Place of publication: publisher or sponsoring organization. Report number. Contract number. Total number of pages. Availability statement if different from publisher or sponsoring organization. (Availability statement may be an internet address for government documents.)

Harris JL and ME Gordon (Department of Biological Sciences, University of Mississippi, Oxford MS). 1988. Status survey of *Lampsilis powelli* (Lea, 1852). Final report 1 Aug 86 – 31 Dec 87. Jackson (MS): US Fish and Wildlife Service, Office of Endangered Species. Report nr USFW-OES-88-0228. Contract nr USFW-86-0228. 44+ p.

US Geological Survey (USGS). 1979. Drainage areas of streams in Arkansas in the Ouachita River Basin. Open file report. Little Rock (AR): USGS. 87 p. <www.usgs.gov/ouachita> Accessed on 2 Dec 2005.

In text Citation: (USGS 1979)

Published Conference Proceedings – General format is given first.

Author(s)/Editor(s). Date of publication. Title of publication or conference. Name of conference (if not given in the 2nd element); inclusive dates of the conference; place of the conference. Place of publication: publisher. Total number of pages.

Vivian VL, editor. 1995. Symposium on Nonhuman Primate Models for AIDS; 1994 June 10-15; San Diego, CA. Sacramento (CA): Grune & Stratton. 216 p.

In-text Citation Form for Multiple Citations

(Harris and Gordon 1988, Steiner et al. 1992, Johnson 2006).

REVIEW PROCEDURE

Evaluation of a paper submitted to the *JOURNAL* begins with critical reading by the Managing Editor. The manuscript is then submitted to referees for critical review for scientific content, originality and clarity of presentation. To expedite review, authors should provide the names and current e-mail address of at least three reviewers within the appropriate field, with whom they have not had a collaboration in the past two years. Potential reviewers that the authors wish to avoid due to other conflicts of interest can also be provided. Attention to the preceeding paragraphs will also facilitate the review process. Reviews will be returned to the author together with a judgement regarding the acceptability of the manuscript for publication in the journal. The authors will be requested to revise the manuscript where necessary. Time limits for submission of the manuscript and publication charges will be finalized in the accompanying letter from the Managing Editor (see "Proposed timetable for manuscript processing"). The authors will then be asked to return the revised manuscript, together with a cover letter detailing their responses to the reviewers' comments and changes made as a result. If the time limits are not met, the paper may be considered withdrawn by the author. Please note that this revised manuscript will be the manuscript that will enter into the bound journal. Thus, authors should carefully read for errors and omissions so ensure accurate publication. A page charge will be billed to the author of errata. All final decisions concerning acceptance or rejection of a manuscript are made by the Managing Editor (Ivan H. Still) and/or the Editor-in-Chief (Mostafa Hemmati).

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Reprint charges will be placed with the printer, not the Managing Editor. Information will be supplied nearer publication of the Journal issue.

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Each issue of the *JOURNAL* is sent to several abstracting and review services. The following is a partial list of this coverage.

Abstracts in Anthroplogy
Abstracts of North America Geology
Biological Abstracts
Chemical Abstracts
Mathematical Reviews
Recent Literature of the Journal of Mammalogy
Science Citation Index
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